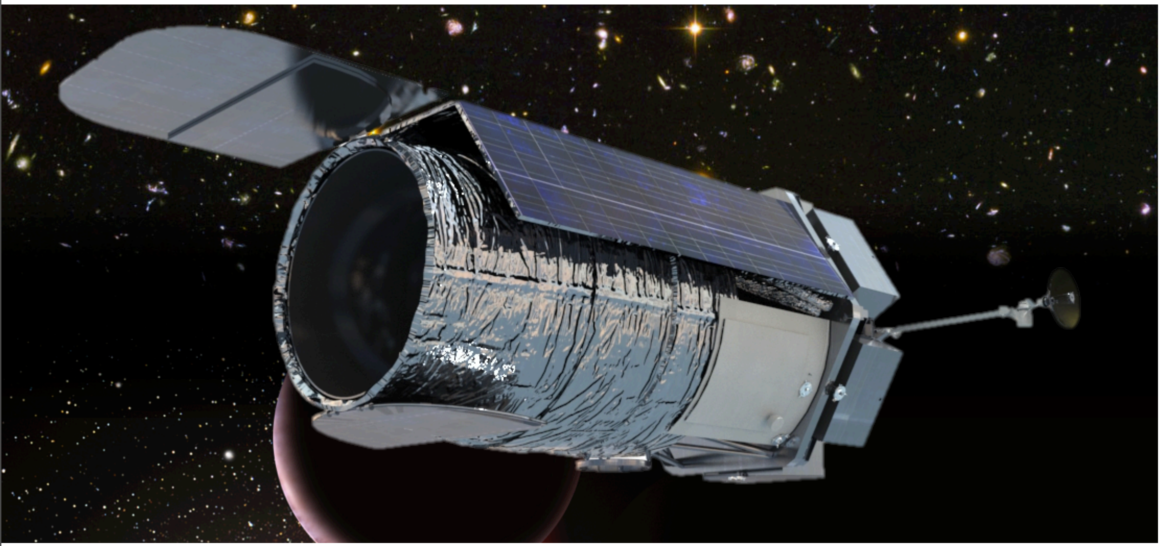
Astrophysics Focused Telescope Assets (AFTA)

Neil Gehrels (GSFC)	SDT Co-Chair
David Spergel (Princeton)	SDT Co-Chair
Kevin Grady (GSFC)	Study Manager & Project Team



SCIENCE DEFINITION TEAM

Charles Baltay, Yale
David Bennett, Notre Dame
James Breckinridge, Caltech
Megan Donahue, Michigan State Univ.
Alan Dressler, Carnegie Observatories
Scott Gaudi, Ohio State Univ.
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Olivier Guyon, Univ. Arizona
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Bernard Rauscher, GSFC
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Dominick Benford, NASA HQ Ex-Officio
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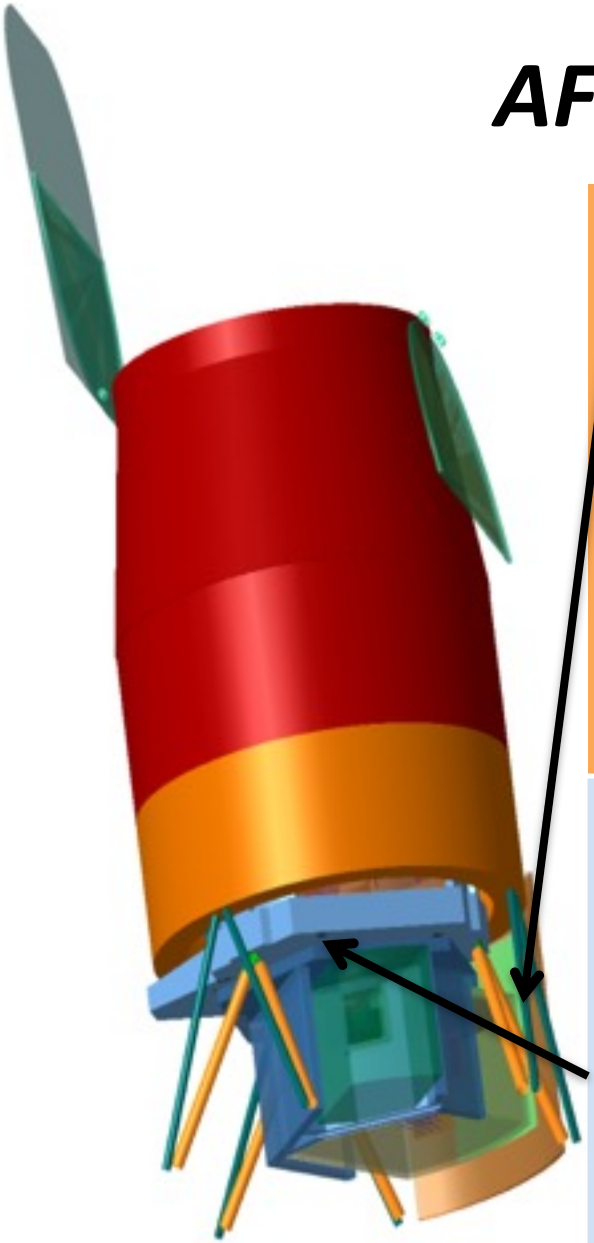
Mike Hudson CSA (Canada)
Yannick Mellier ESA (Europe)
Toru Yamada JAXA (Japan)

AFTA Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

Coronagraph (compelling option)

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- 10^{-9} contrast
- 100 milliarcsec inner working angle at 400 nm

Requires focused tech. development ASAP for 2021 launch

Next Steps

- **Coronagraph included now as a baseline instrument**

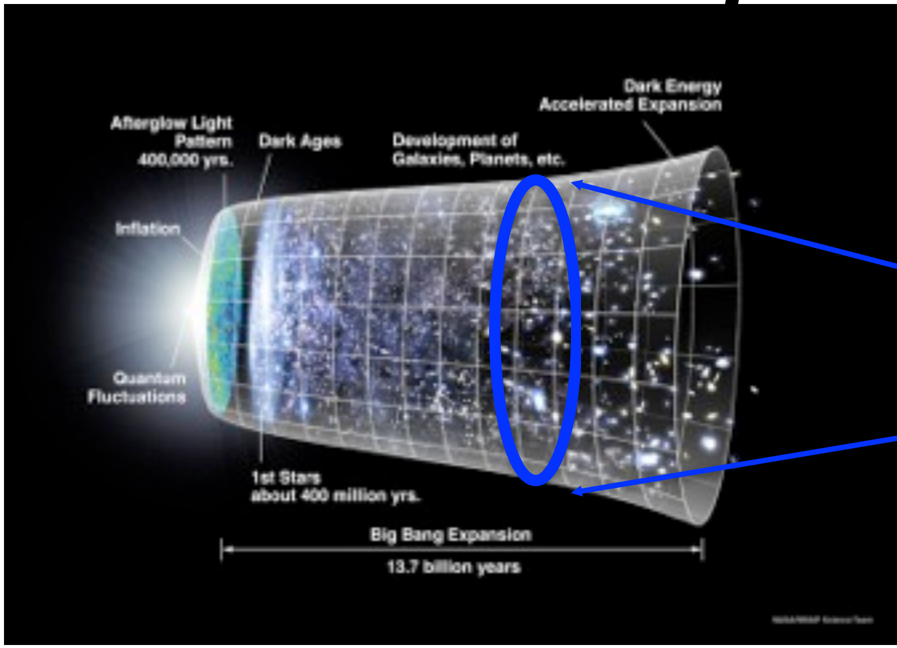
- Coronagraph primary architectures selected (see Kasdin talk)
- Small IFU instrument included for multi-object slit spectroscopy
- Project office (GSFC + JPL) active in observatory designs and technology advancement
- SDT and project study areas:
  * Detailed requirements flowdown
  * Observatory performance relative to NWNH goals
  * Trades of telescope temperature and wavelength red limit
  * Survey strategies, accounting for LSST, JWST, Euclid, …. synergies
  * Microlensing strategies, accounting for ground observation synergies
  * Coronagraph strategies, accounting for Kepler, TESS, RV program, …. synergies
  * Observatory uses across astrophysics (ExoPAG, COPAG, PhysPAG)
  * Role of a robust GI and GO program
  * Options for NASA science team selection process

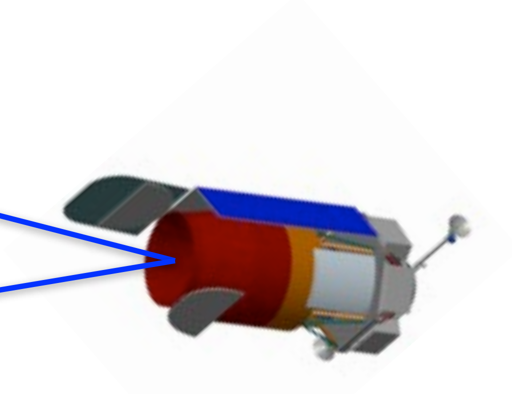
AFTA is well matched to the WFIRST Requirements

- Existing Hardware: high quality mirror and optical system
- Easily used in Three Mirror Anastigmat (TMA)
  - Wide field of view
  - 3^{rd} mirror in Wide-Field instrument
- AFTA's 2.4 m aperture + wide field imager meets (and exceeds) WFIRST requirements:
  - Higher spatial resolution enhances science capability
  - Larger collecting area enables more science in fixed time
- AFTA's 2.4m aperture enables richer scientific return at much lower cost than a dedicated smaller coronagraphic telescope mission

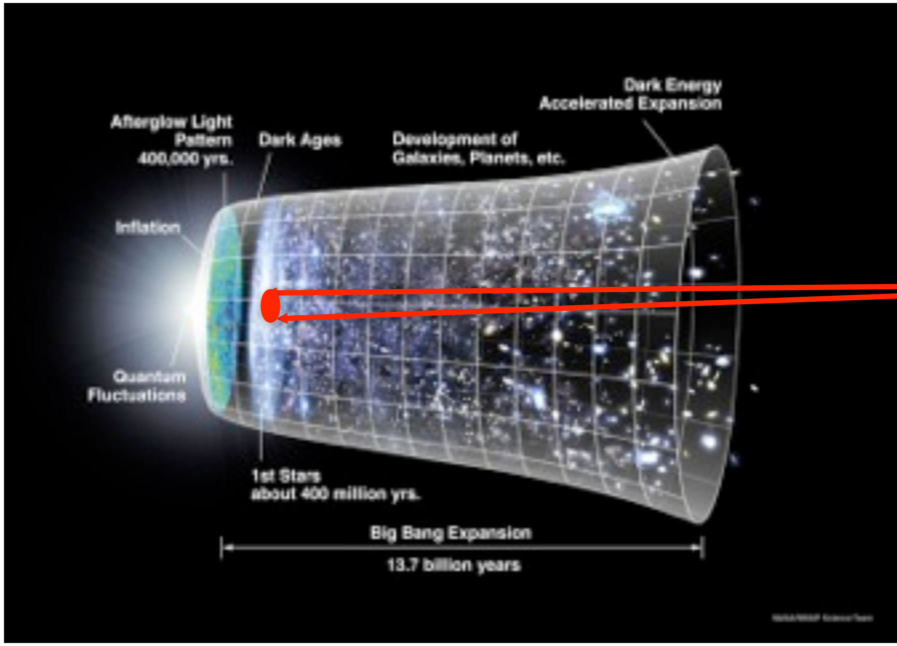
Study concluded that these assets satisfy all mission requirements.

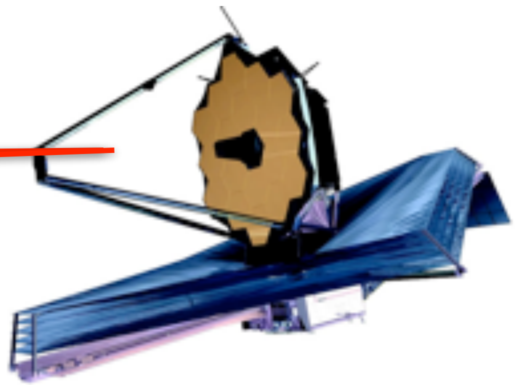
AFTA Complements JWST





WIDE!



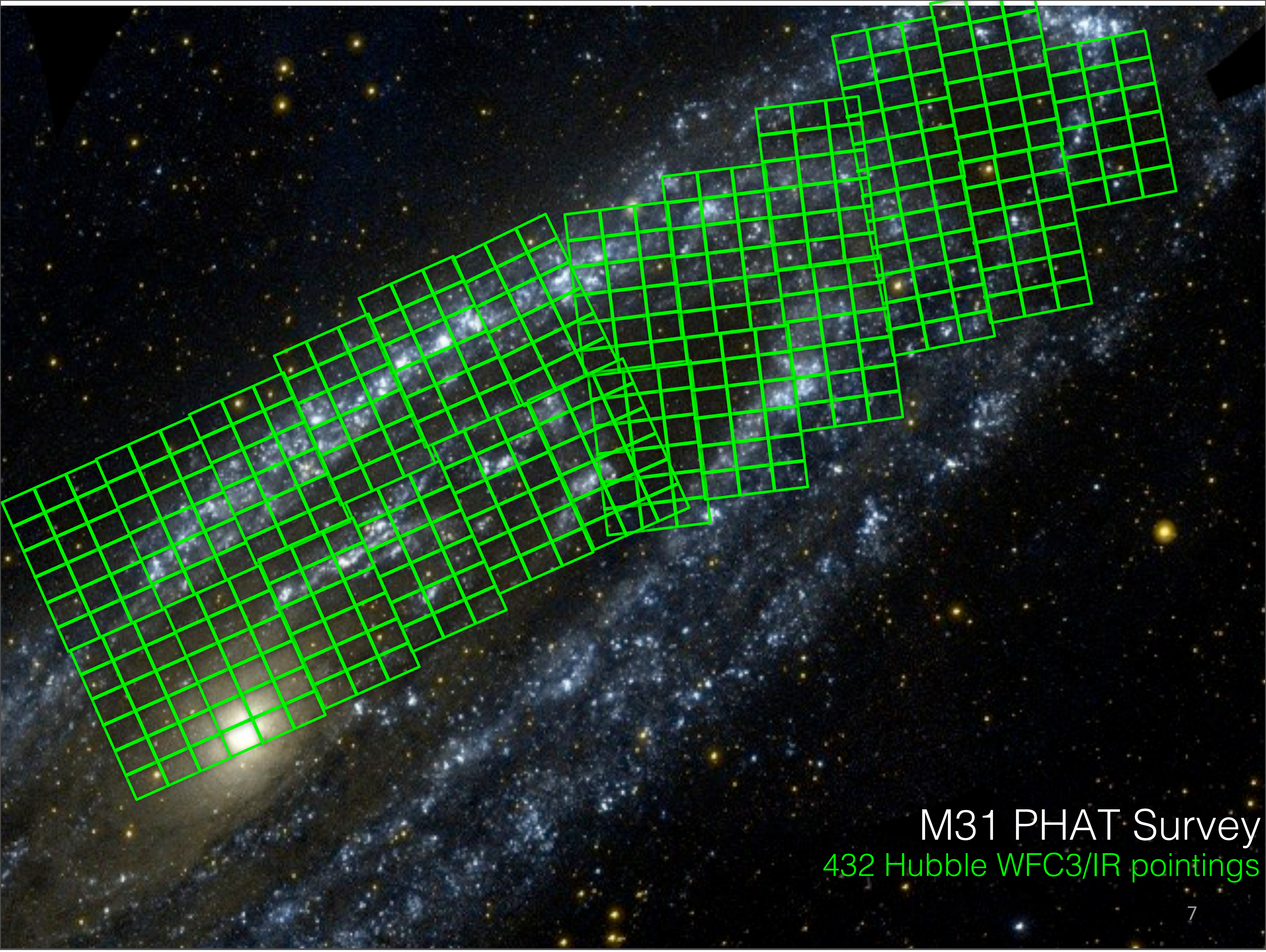


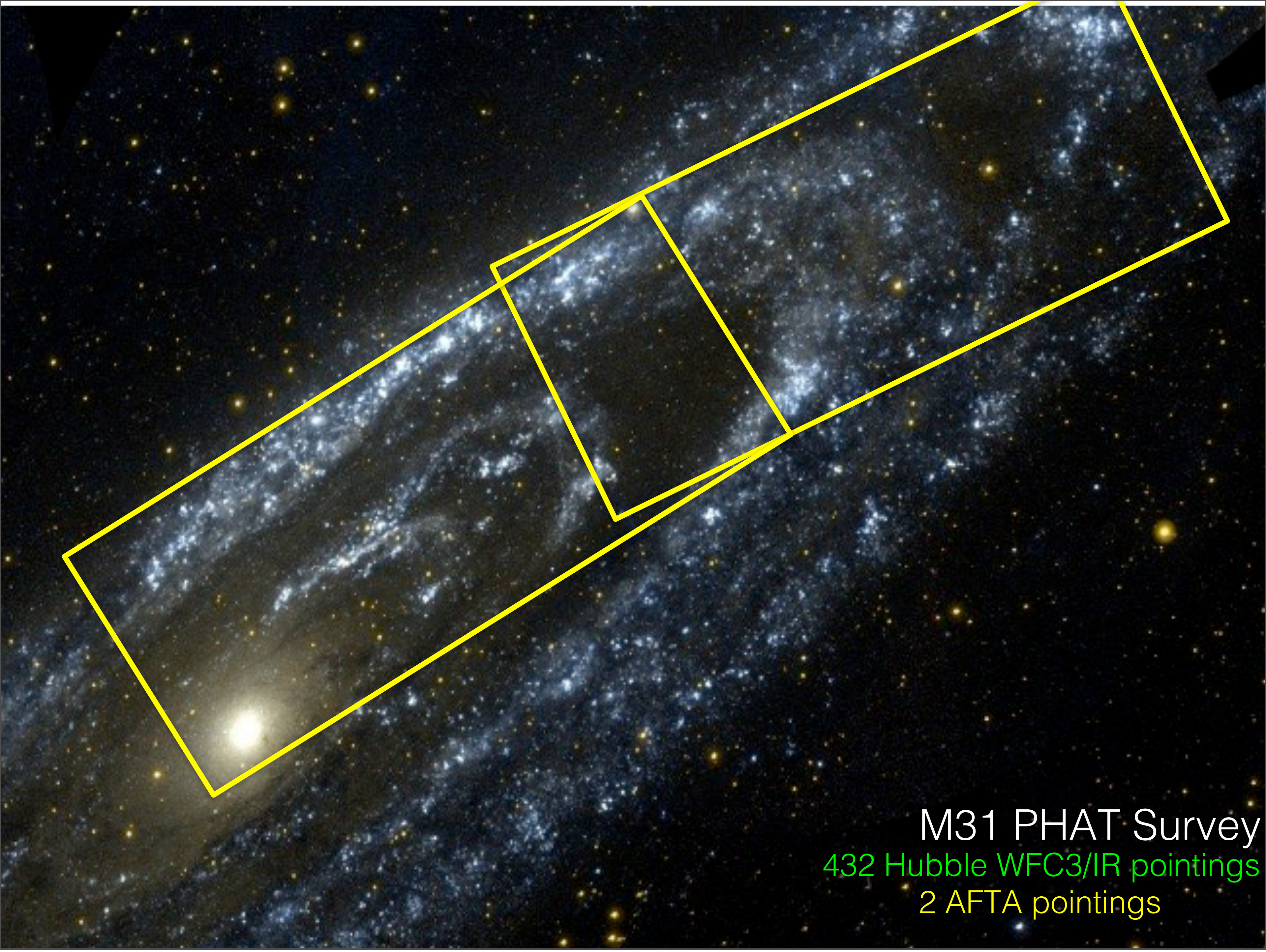
DEEP!

“Bright” Galaxy Survey

- Four Surprisingly bright (26-27 AB) galaxies at z~9 in HST CANDELS WFC3/IR imaging data (Oesch et al. 1309.2280, AAS 223)
- WFIRST will find ~10,000 bright galaxies (and perhaps significant number at higher redshift)
- Important targets for JWST and large ground-based telescopes


M31 PHAT Survey


M31 PHAT Survey
432 Hubble WFC3/IR pointings

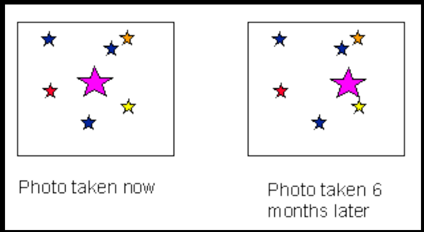

M31 PHAT Survey
432 Hubble WFC3/IR pointings
2 AFTA pointings

Astrometry with AFTA

- Smaller PSF (factor 2) and higher photon flux implies that AFTA can achieve the same level of photometric accuracy 9x faster than previous version of WFIRST
- Opens up a wide range of new science
    - dark matter properties through studying tidal tails, dwarf galaxies
    - exoplanet science

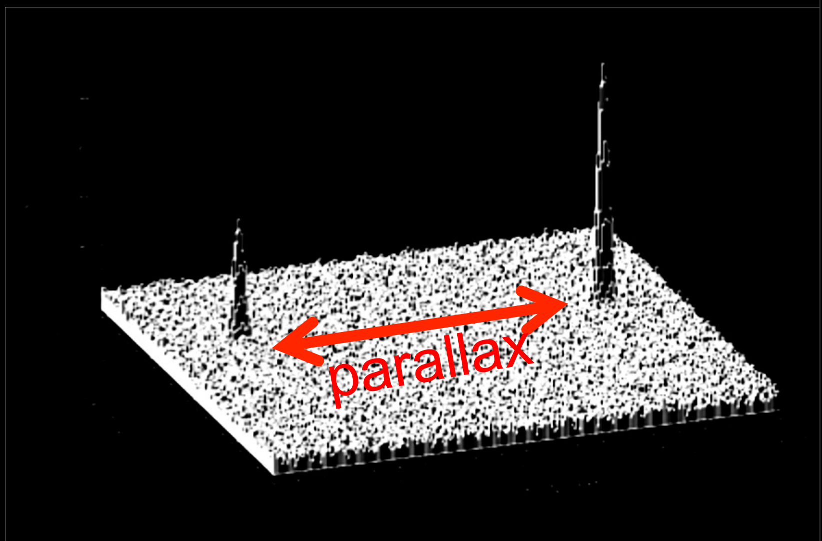
FROM ADAM RIESS

Precision Astrometry with Spatial Scanning (PASS)

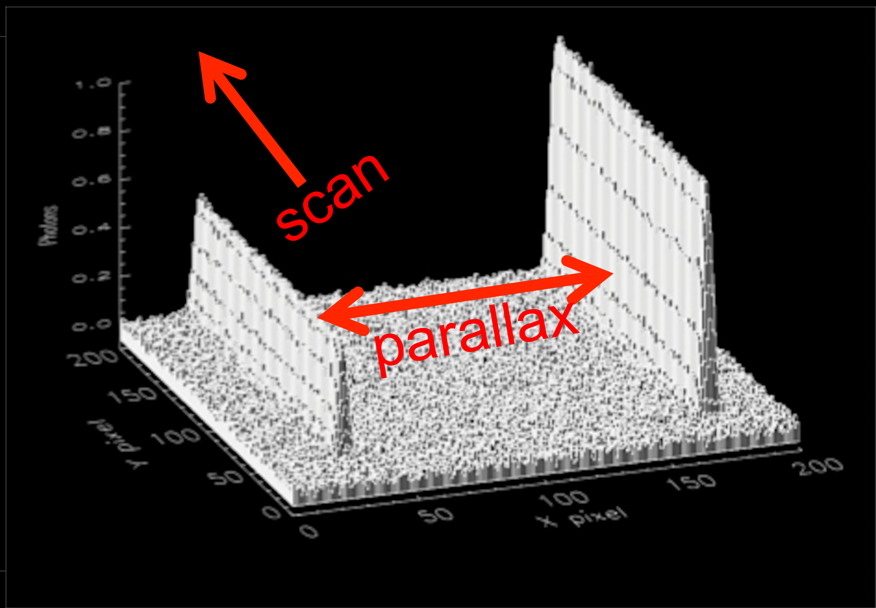


WFC3-UVIS, 0.01 pixel=400 µas~2σ @ 2 kpc

Imaging, PSF σ_θ=0.01 pix



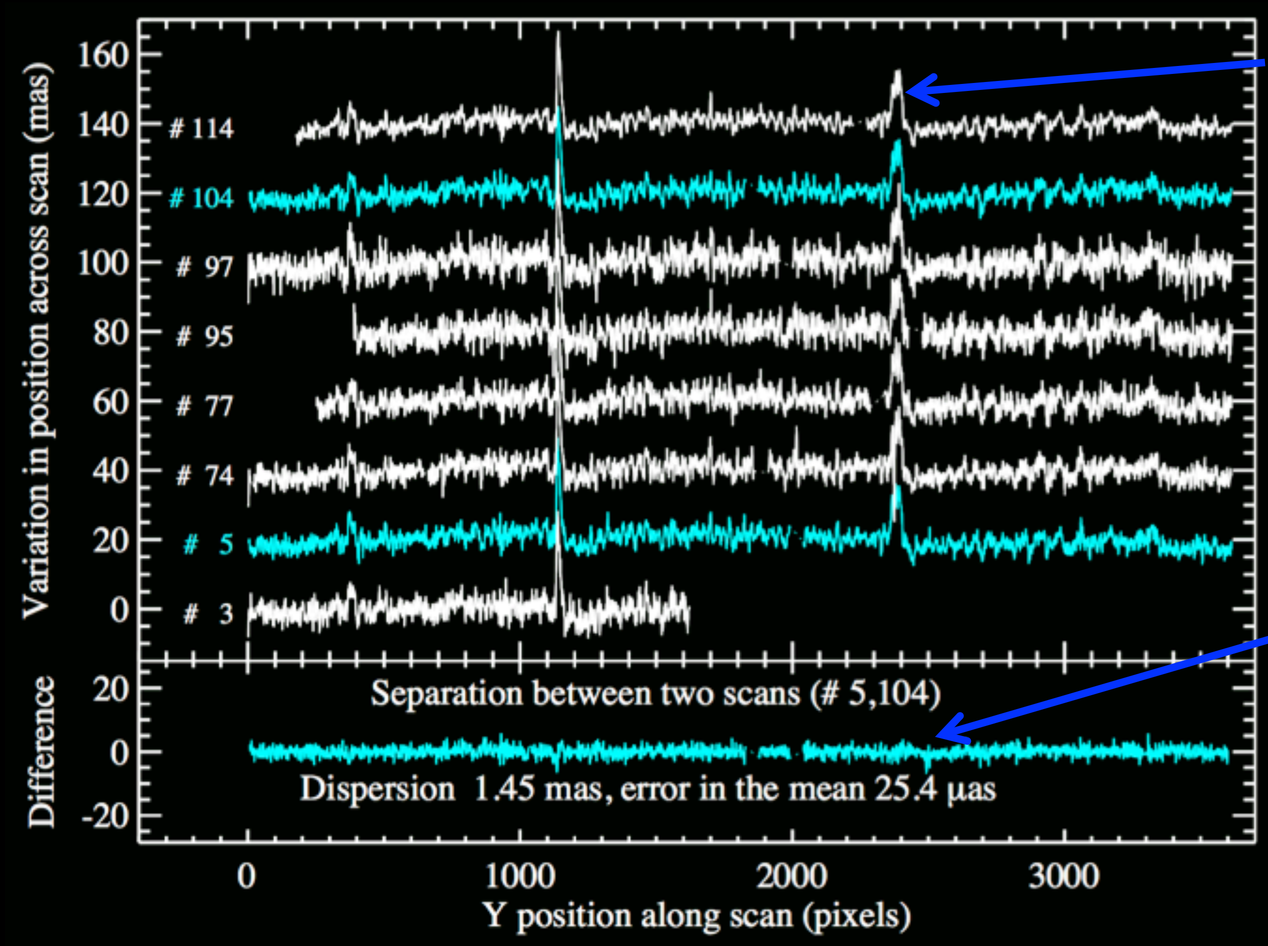
Scanning, $\sigma_\theta=0.01/\sqrt{N \text{ samples}}$ pix



FROM ADAM RIESS

Two Features of Spatial Scans, Jitter and Repetition

Average all scan lines to produce “reference line”

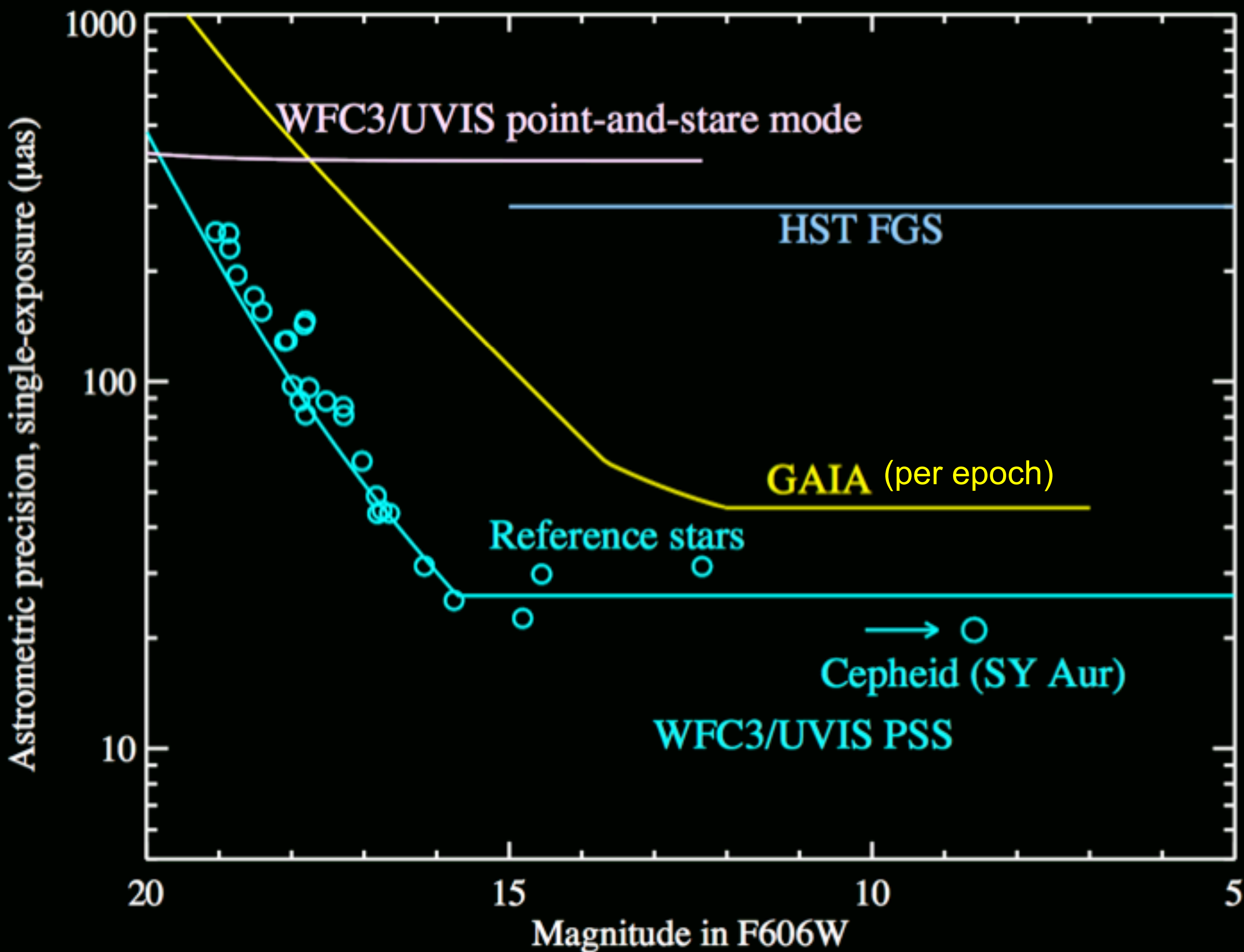


Jitter between lines is *coherent*, subtracted in line separations (vs time) *approach is doubly differential*

Target scanned over ~4000 pix, improves snr by up to ~40 (or 10 for correlated errors on scales of 40 pix)

FROM ADAM RIESS

Astrometric Precision Per Exposure



Need high snr *per pixel* so bright targets give best results (350 sec scan In F606W)

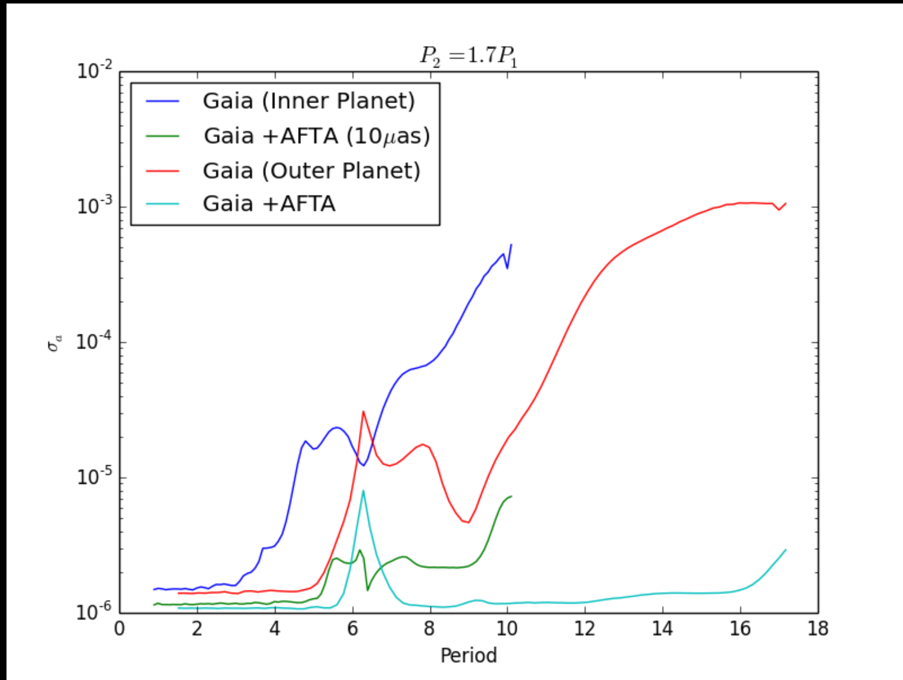
And we can measure Cepheid photometry on same system

AFTA + Scanning Astrometry

- Bigger camera should enable improved sensitivity- scales as $\sqrt{N_{pixel}}$
- At J=12, S/N = 400 and saturate central pixel in one second (WFC3 simulator).
- In a 3 minute integration, stars brighter than J = 17.5 are saturated.
- Scan at 3 degree/minute = 1600 pixels/second
- Spreads signal over 24,000 pixels
  - Assume 5x improvement over HST's 1/2000th pixel performance or 1/50th of a pixel /$\sqrt{24,000}$ (7 μas)
- Repeated 30 second integration. Achieves 10 μas astrometry for J < 9 in each integration, 50 μas for the ~30 stars with J < 13 and 200 μas for ~200 stars with J < 18
- Saturates for J = 4 at 3 deg./min, J = 3 at 10 deg/min

Nearby K and M Star Survey

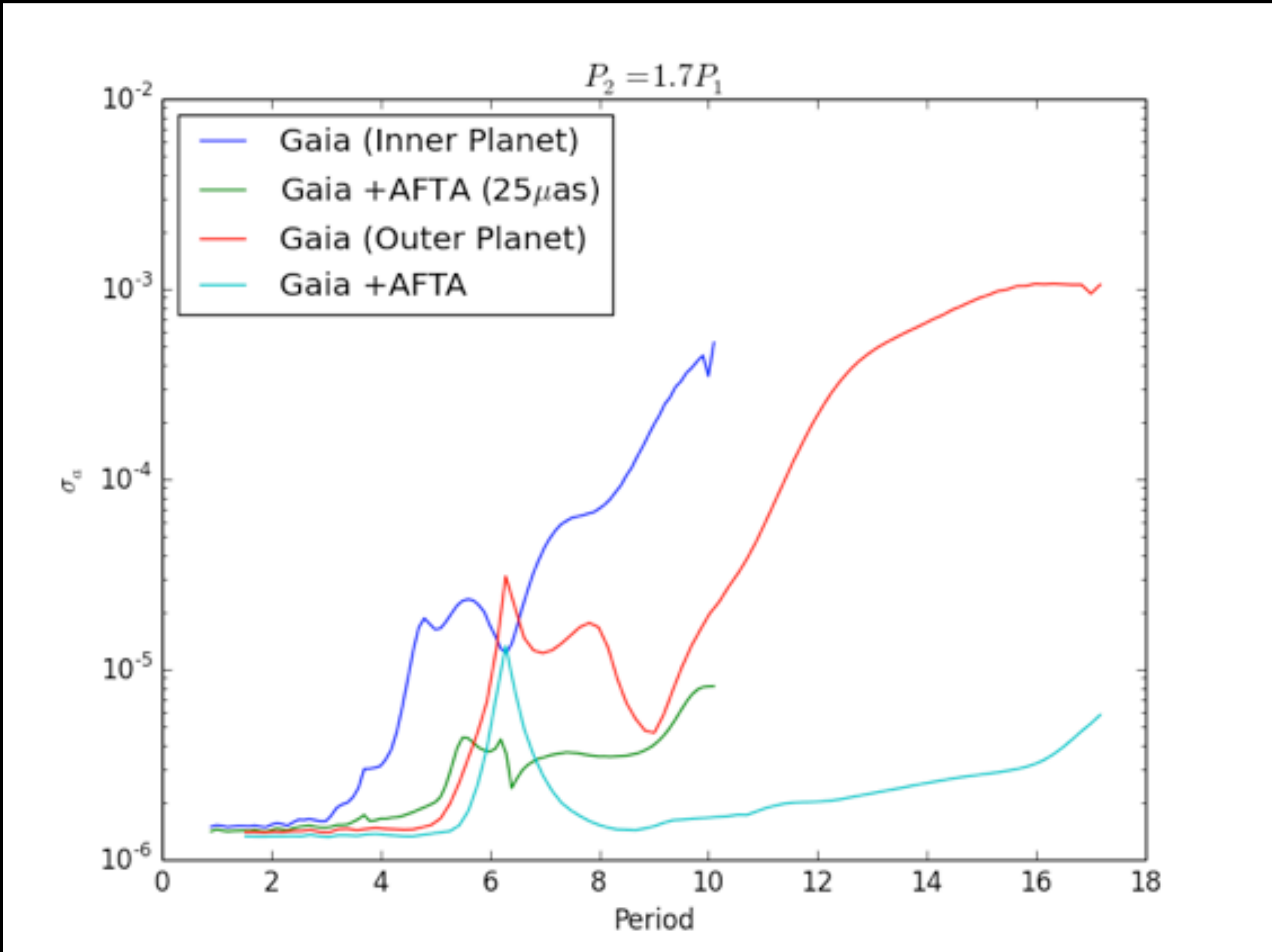
- Combine GAIA and AFTA data for $5 < V < 12$ and $J > 3$ stars.
- Make use of 15 year baseline!
- 119 stars (G8-M4.5) d< 10 pc
- Can detect Earth mass planets around nearby stars with period less than 18 yr
- 8400 obs. x (0.5 min +overhead)



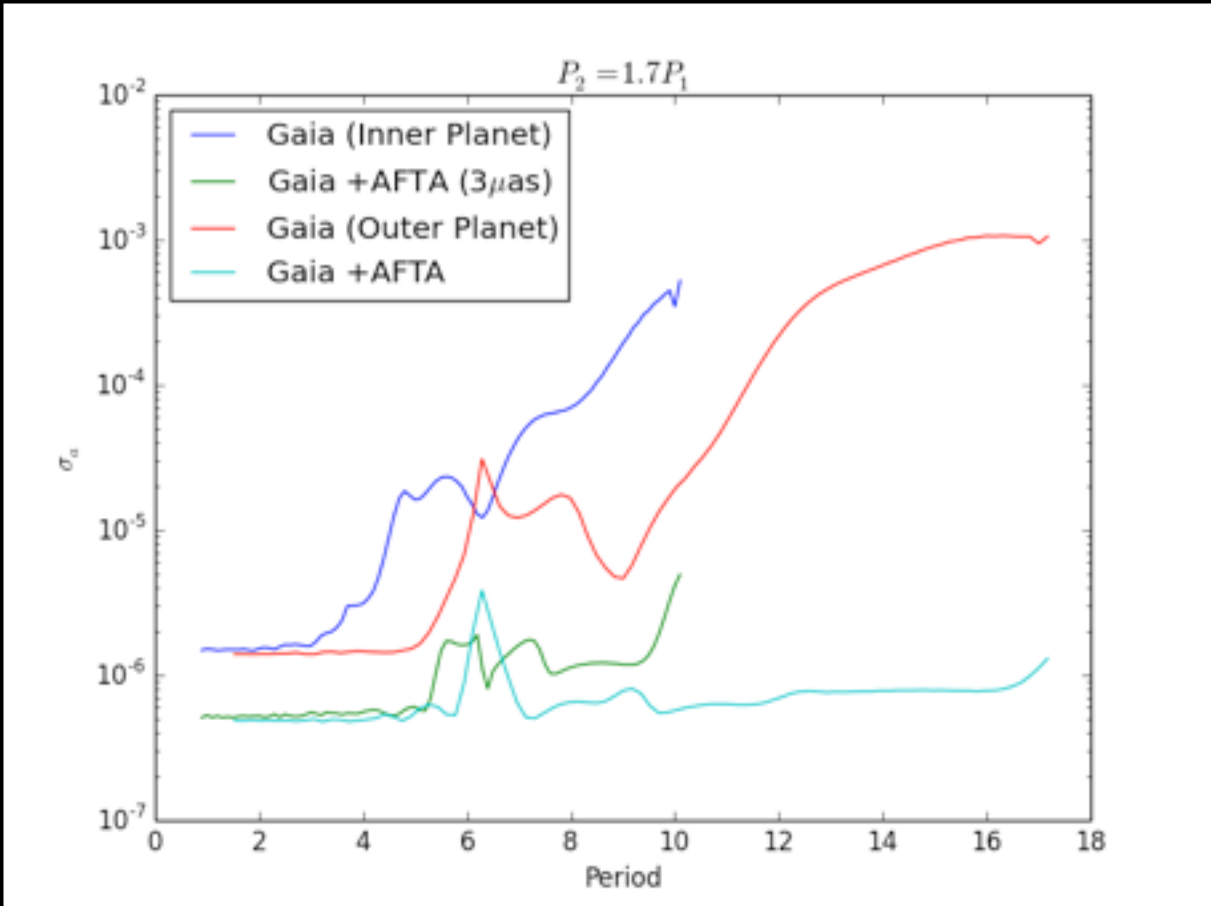
- Estimate sensitivity based on 70 Gaia + 70 AFTA observations and Fisher mtrix for 19 parameters (position, prop. motion, parallax and 2 planets x 7 parameters)

$$M_p > 3\ M_{\rm Earth} \left(\frac{d}{7\ {\rm pc}}\right) \left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3} \left(\frac{\tau}{3\ {\rm yr}}\right)^{-2/3}$$

2x HST astrometry - 25 μas



Optimistic Case (10 repeated slews x70 observations)



$$M_p > M_{\rm Earth}\left(\frac{d}{7\ {\rm pc}}\right)\left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3}\left(\frac{\tau}{3\ {\rm yr}}\right)^{-2/3}$$

Astrometry + Weak Lensing

- Augment HLS with a quick astometric observation to tie the ~1000 K =17.5 - 20.5 mag stars to the GAIA grid with sub-mas astrometry. At high latitudes, there are 10 Gaia stars with positions better than 10 μas positions and 100 stars with 25 μas positions
- Very accurate determination of aberrations in each image. Significantly better than science requirements for imaging survey
  - Ratio of image distortion to astrometric displacement is roughly proportional to ratio of image size to FOV!

Conclusions

- AFTA effectively achieves the decadal survey WFIRST goals and open up new science opportunities accross a broad range of astrophysics

Backup

House Authorization

Sec. 312 – Extrasolar Planet Exploration Strategy.

This section would state that the Administrator shall contract with the National Academies to develop a strategy for the study and exploration of extrasolar planets. The strategy would provide a foundation for NASA roadmaps, strategic plans, and activities related to exoplanet research and exploration.

Sec. 314 – Wide-Field Infrared Survey Telescope.

This section would state that the Administrator shall ensure that the development of the WideField Infrared Survey Telescope continue while the James Webb Space Telescope is completed.

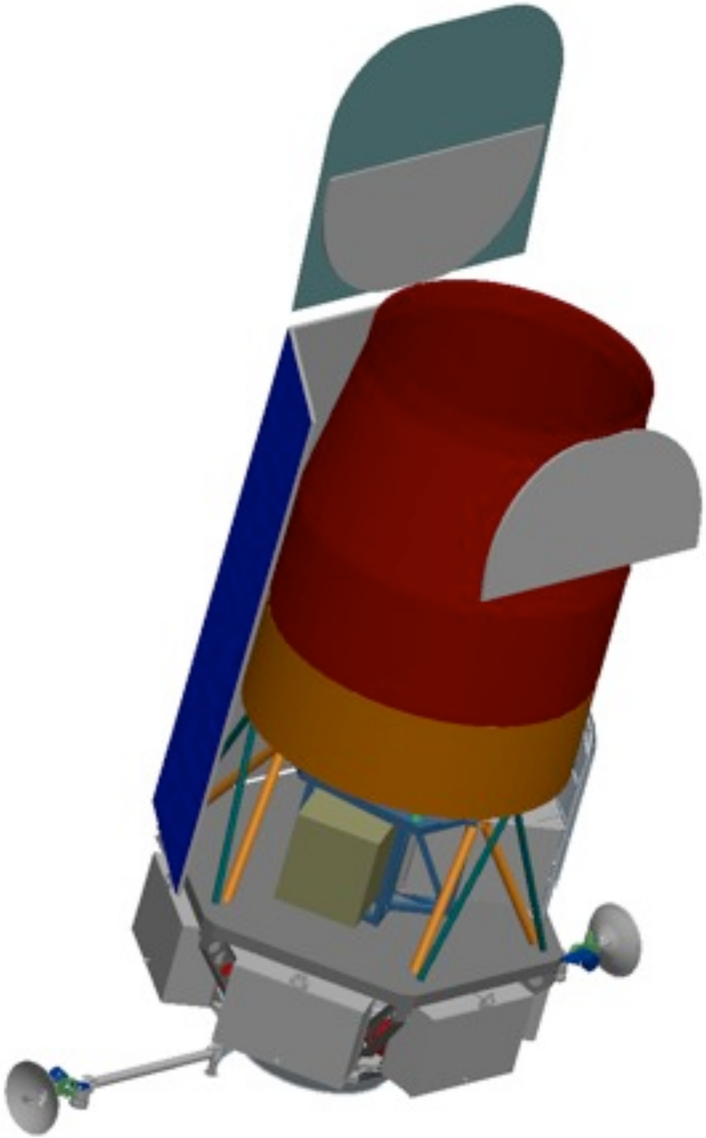
Sec. 315 – National Reconnaissance Office Telescope Donation

This section would require the Administrator to transmit a report to Congress outlining NASA's plan for developing the Wide-Field Infrared Survey Telescope including an alternative plan for the Wide-Field Infrared Survey Telescope 2.4, which includes the donated 2.4-meter aperture National Reconnaissance Office telescope. The plan shall include: an assessment of affordable approaches to develop the Wide-Field Infrared Survey Telescope; a comparison to the development of mission concepts that exclude the utilization of the donated asset; an assessment of how NASA's existing science missions will be affected by the utilization of the donated asset; and a description of the cost associated with storing and maintaining the donated asset.

Senate Appropriation

WFIRST Science Mission.-Within the funds provided, the Committee provides $56,000,000 for NASA to proceed with design studies, further technical risk reduction, and detailed formulation on a science mission that meets the exoplanet and dark energy science objectives of WFIRST. This recommendation corresponds with findings from NASA's May 23, 2013, report on Astrophysics Focused Telescope Assets, and should build upon the Agency's work with

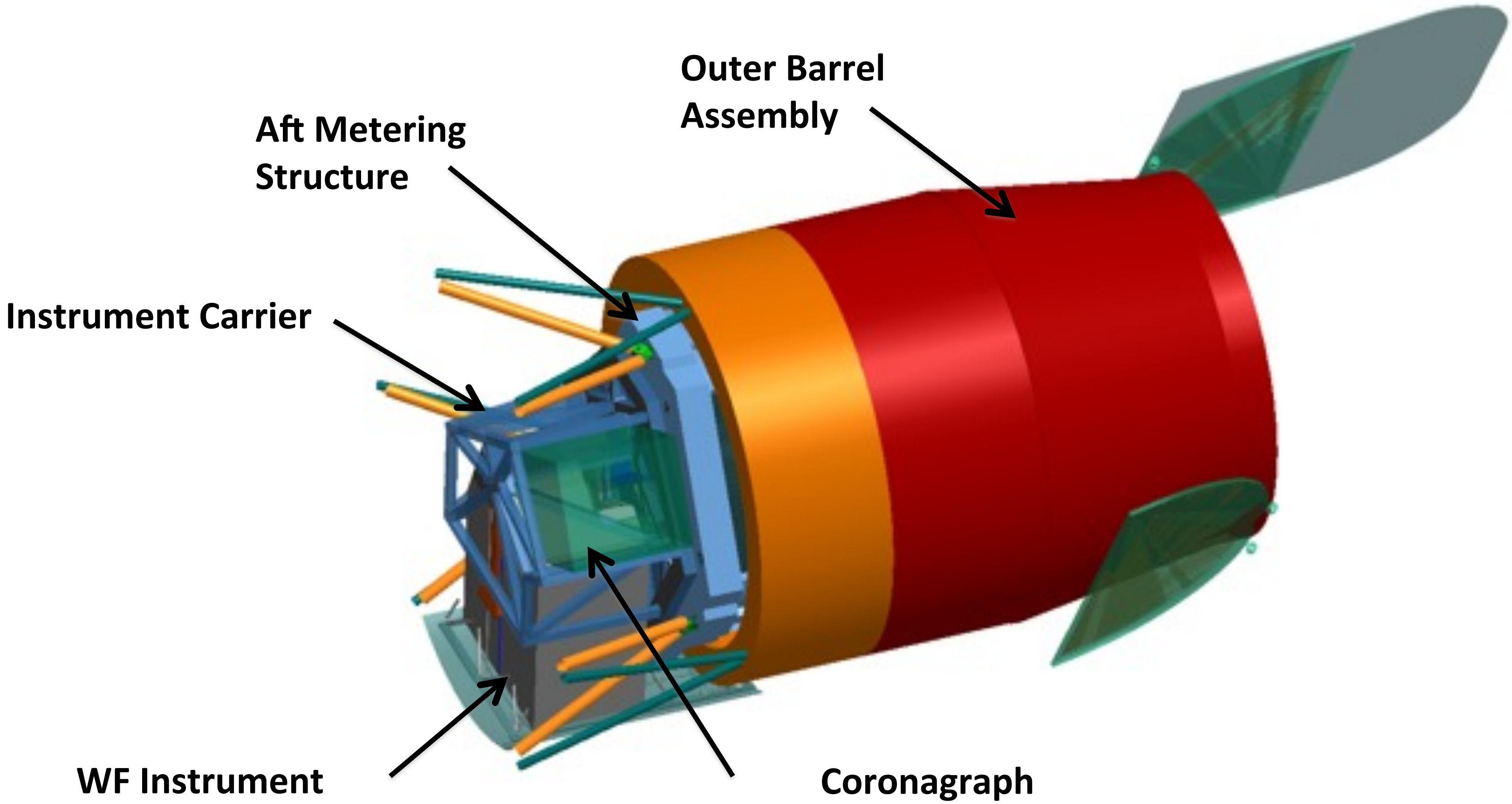
AFTA Observatory Concept



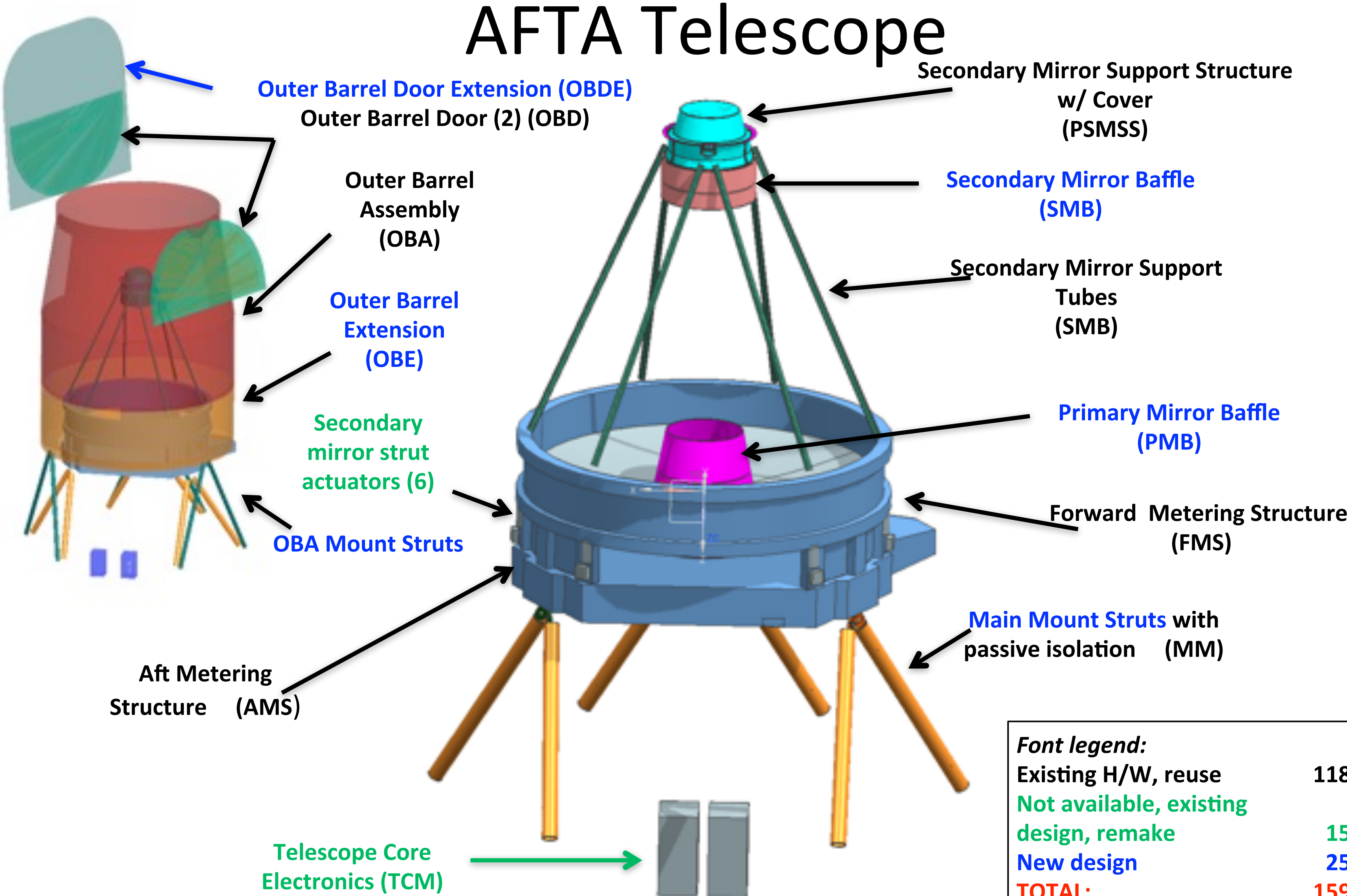
Key Features

- Telescope – 2.4m aperture primary
- Instrument – Single channel widefield instrument, 18 HgCdTe detectors; integral field unit spectrometer incorporated in widefield for SNe observing
- Overall Mass – ~6850 kg with components assembled in modules; (~3100 kg fuel)
- Primary Structure – Graphite Epoxy
- Downlink Rate – Continuous 150 mbps Ka-band to Ground Station
- Thermal – passive radiator
- Power – 2800 W
- GN&C – reaction wheels & thruster unloading
- Propulsion – bipropellant
- GEO orbit
- Launch Vehicle – AtlasV 541

AFTA Payload Design Concept



AFTA Telescope

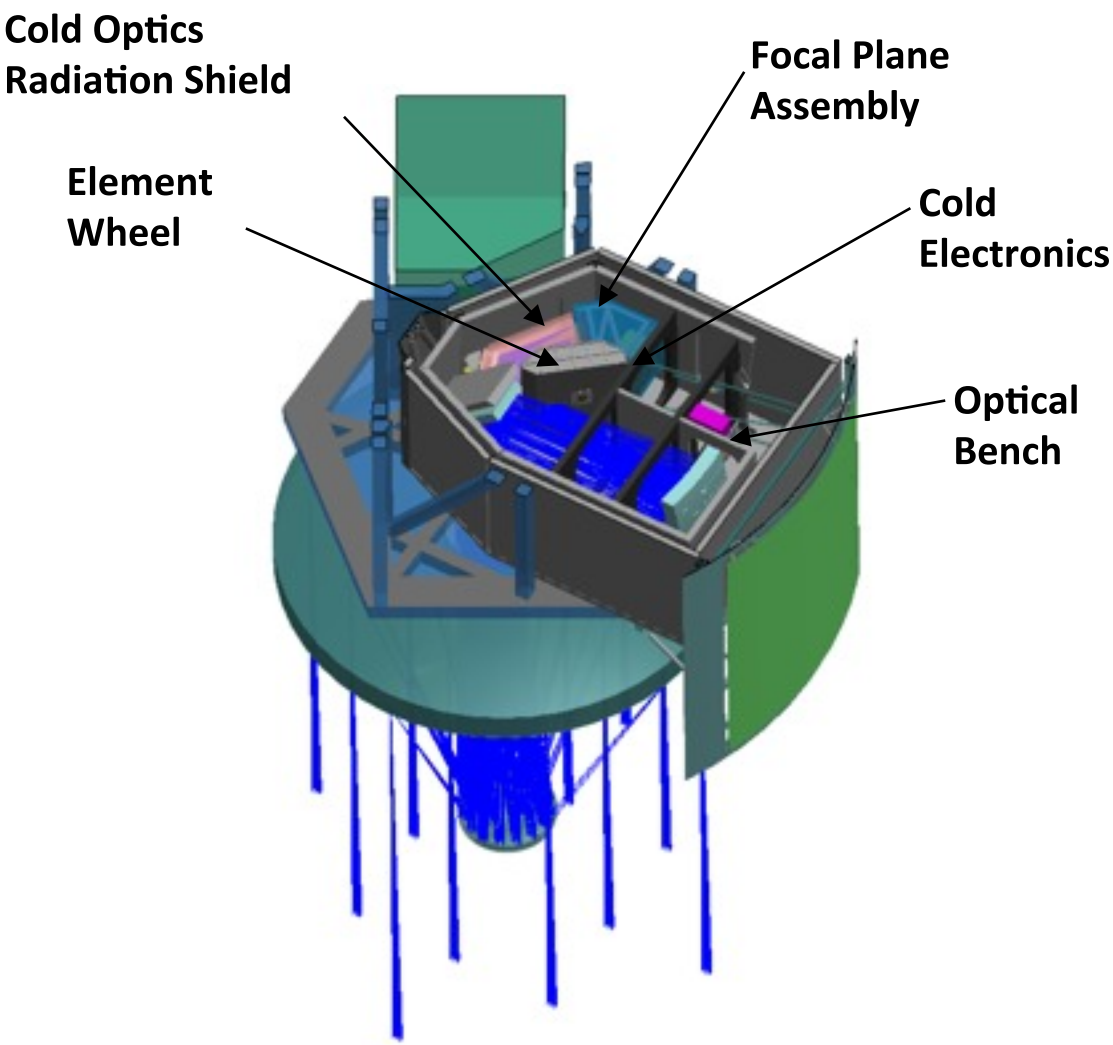


Font legend:	
Existing H/W, reuse	1188 kg
Not available, existing design, remake	153 kg
New design	254 kg
TOTAL:	1595 kg

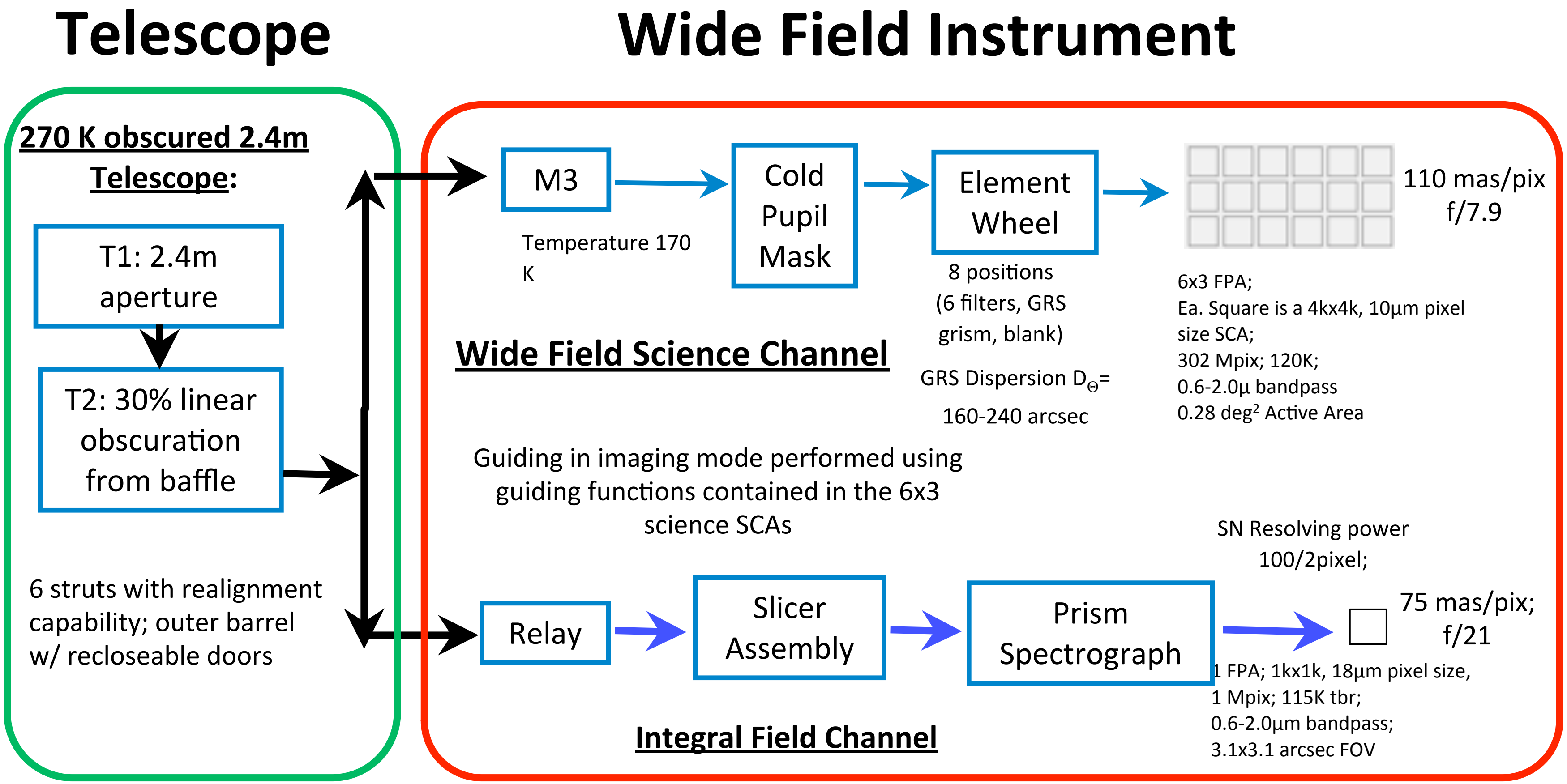
100% of the existing telescope hardware is being re-used. Minor PM & SM refigure. Actuators, electronics and baffles not available and must be replaced.

Widefield Instrument Layout

- Single widefield channel instrument
- 3 mirrors, 1 powered
- 18 4K x 4K HgCdTe detectors
- 0.11 arc-sec plate scale
- IFU for SNe spectra, single HgCdTe detector
- Single filter wheel
- Grism used for GRS survey
- Thermal control – passive radiator



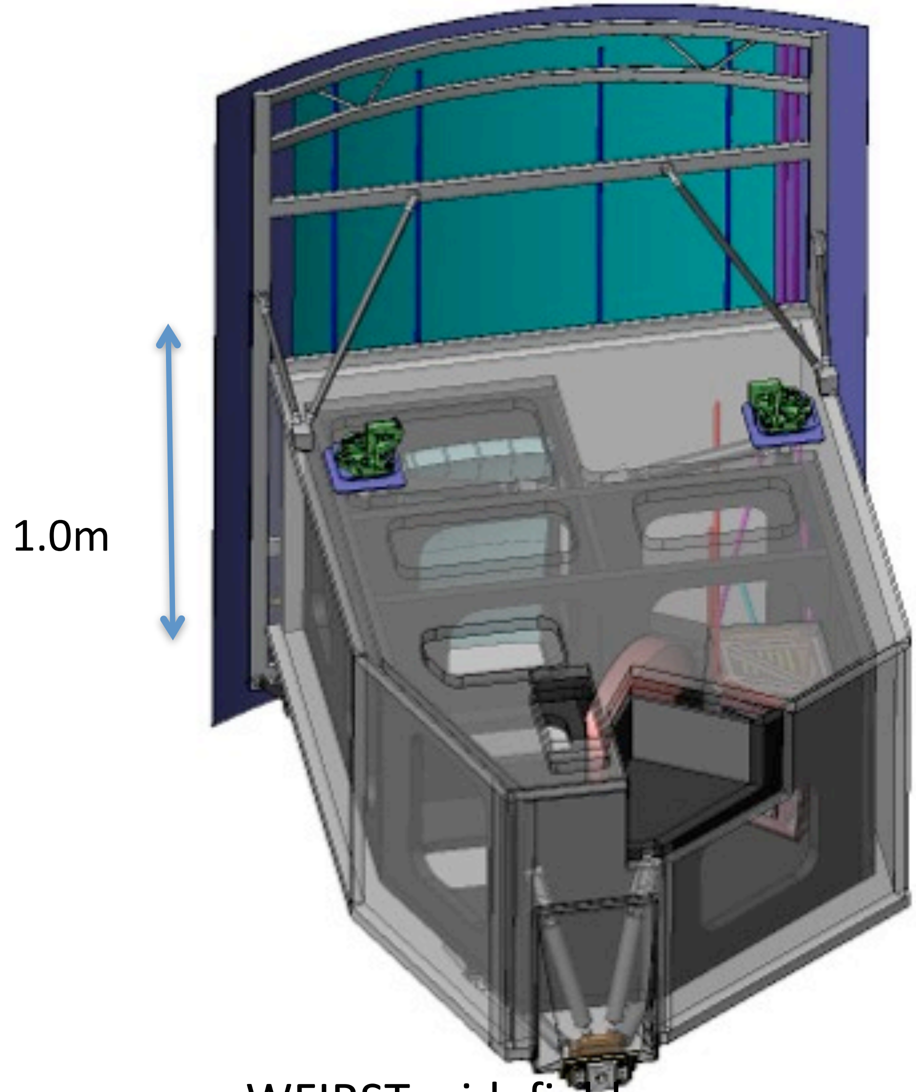
AFTA Payload Block Diagram



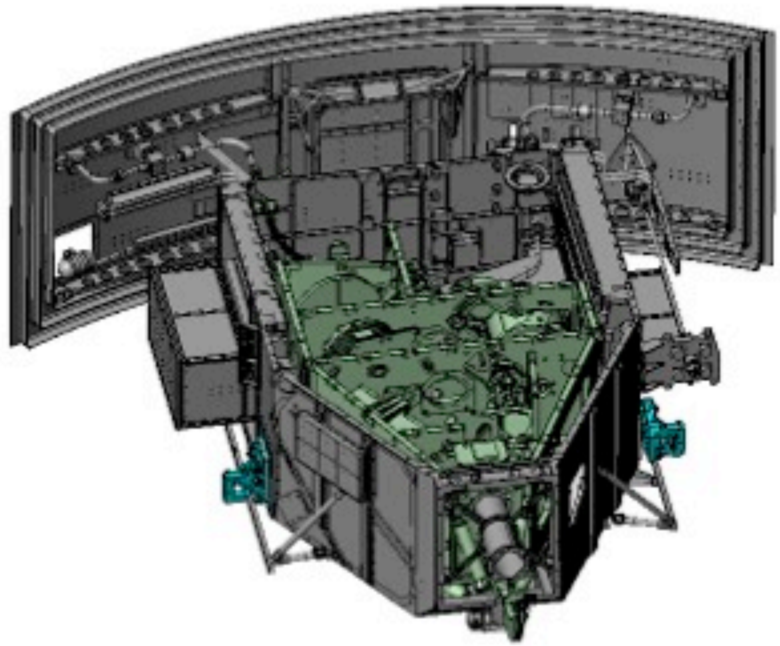
GRS = Galaxy Redshift Survey
SCA = Sensor Chip Assembly
SN = Type1a Supernovae

2 fold mirrors in WF channel and 3 TBR in IFC not shown

Widefield Instrument Shares Architecture and Heritage with HST/WFC3



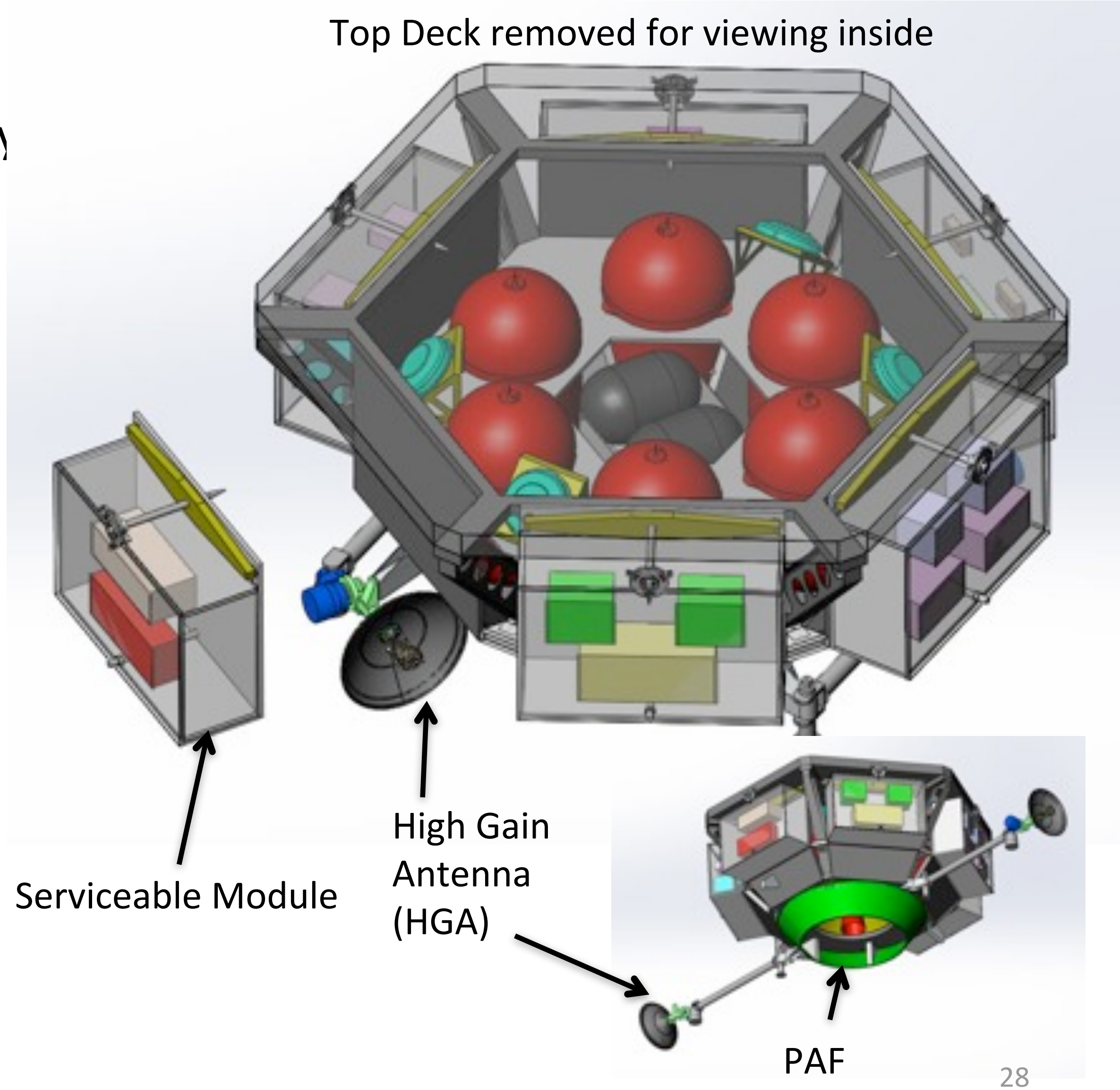
WFIRST widefield



HST/WFC3

Spacecraft Concept

- Spacecraft bus design relies on recent GSFC in-house spacecraft designs, primarily SDO and GPM
- 6 serviceable/removeable modules
  - Power
  - Communications
  - C&DH
  - Attitude Control
  - Telescope Electronics
  - Wide Field Electronics
- Latch design reused from Multimission Modular Spacecraft (MMS)
- 2 deployable/restowable HGAs
- AtlasV 541 Payload Attach Fitting (PAF)
- 6 propellant tanks



Cost & Schedule

Cost Assumptions

- Life-cycle cost developed assumes the use of an existing 2.4m aperture telescope.
- Six and one-half year development phase is assumed. Details in next chart. In the coronagraph option, the payload and observatory I&T phases are increased a total of three months.
- Five year operational phase baselined in cost. For the coronagraph option, an additional year of operations is assumed.
- Cost developed using a combination of grassroots and parametric modeling, along with historical analogous GSFC missions.
- Life-cycle costs are presented for two schedule scenarios
  - The first assumes WFIRST-AFTA is developed along an optimal funding timeline, unconstrained by budget guidelines, resulting in the lowest baseline cost to compare against previous DRM estimates. This baseline is also used to later develop the cost for other what-if funding scenarios.
  - The second schedule scenario assumes pre-phase A studies continue through FY16, with Phase A beginning in FY17.
- Costs are presented in fixed year dollars (FY13) and real year dollars, with an estimate of the total number of equivalent work years.
- Ground system costs include the build of one ground antenna, with an existing antenna used as the back-up.

Comparison of Complexity/Risk/Cost of AFTA to Previous IR Survey DRMs (1/2)

- AFTA incorporates existing telescope - ensures optics not on critical path.
- Early delivery of AFTA telescope allows for extended testing with widefield instrument (15 months). Early testing of widefield instrument (with EDU focal plane) and telescope significantly reduces risk and simplifies instrument/payload GSE requirements.
- AFTA contains a single widefield channel, IDRM had 3 widefield channels.
- AFTA contains ½ the total number of science HgCdTe detectors, reducing instrument integration time *on the critical path.*
- IFU channel adds a 19^{th} detector and electronics chain to the instrument. Additional IFU optics are small and high TRL. R75 (SNe) disperser eliminated. IFU allows simplification of spacecraft design due to decreased roll angle pointing requirement and relaxed revisit pointing requirements.
- Retained conservative 79 month development schedule, same as IDRM, in spite of all of the above simplifications.
- Operations are greatly simplified by eliminating DSN overhead and scheduling requirements. Transmitter operates under steady thermal conditions.

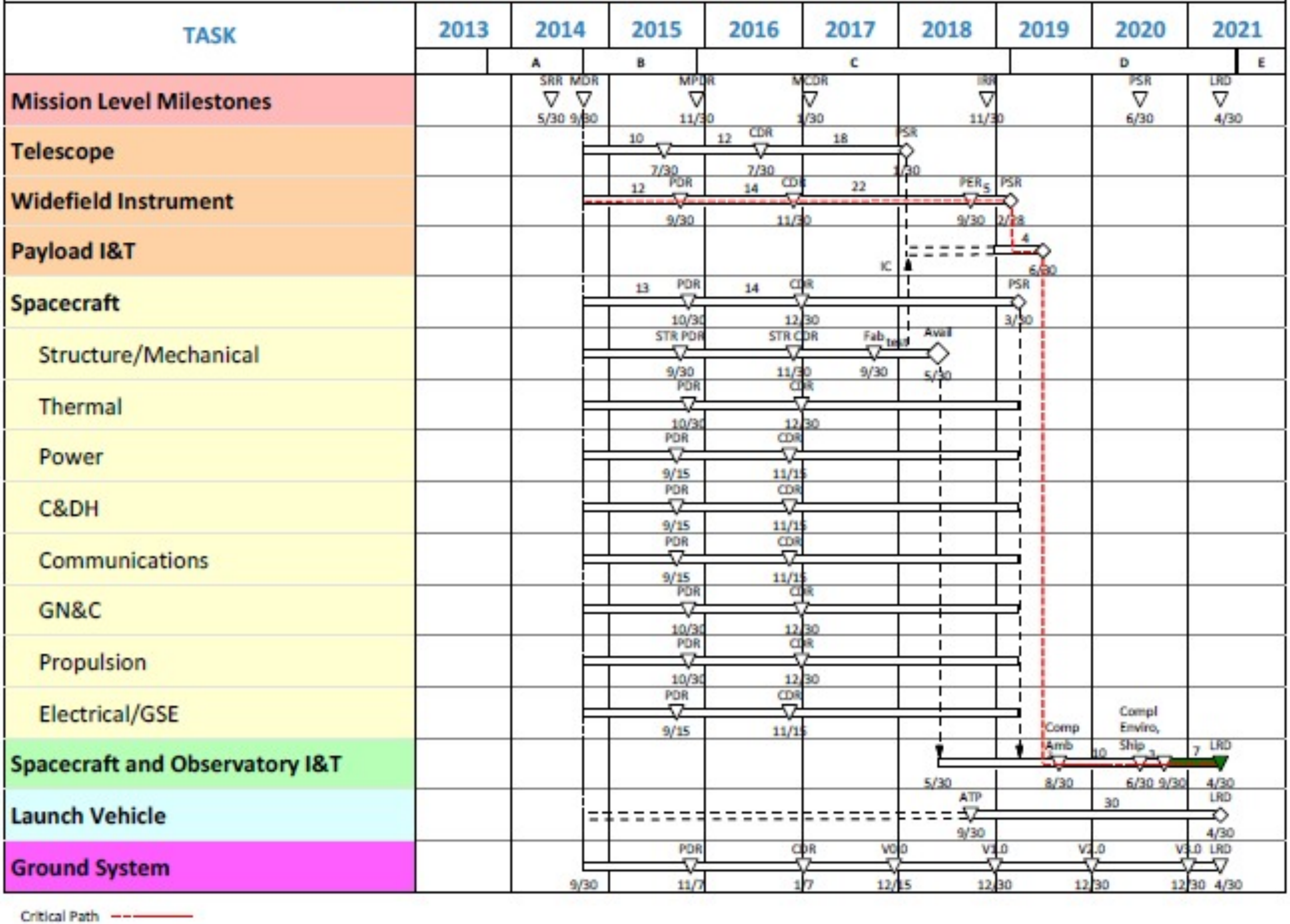
Comparison of Complexity/Risk/Cost of AFTA to Previous IR Survey DRMs (2/2)

Conclusion:

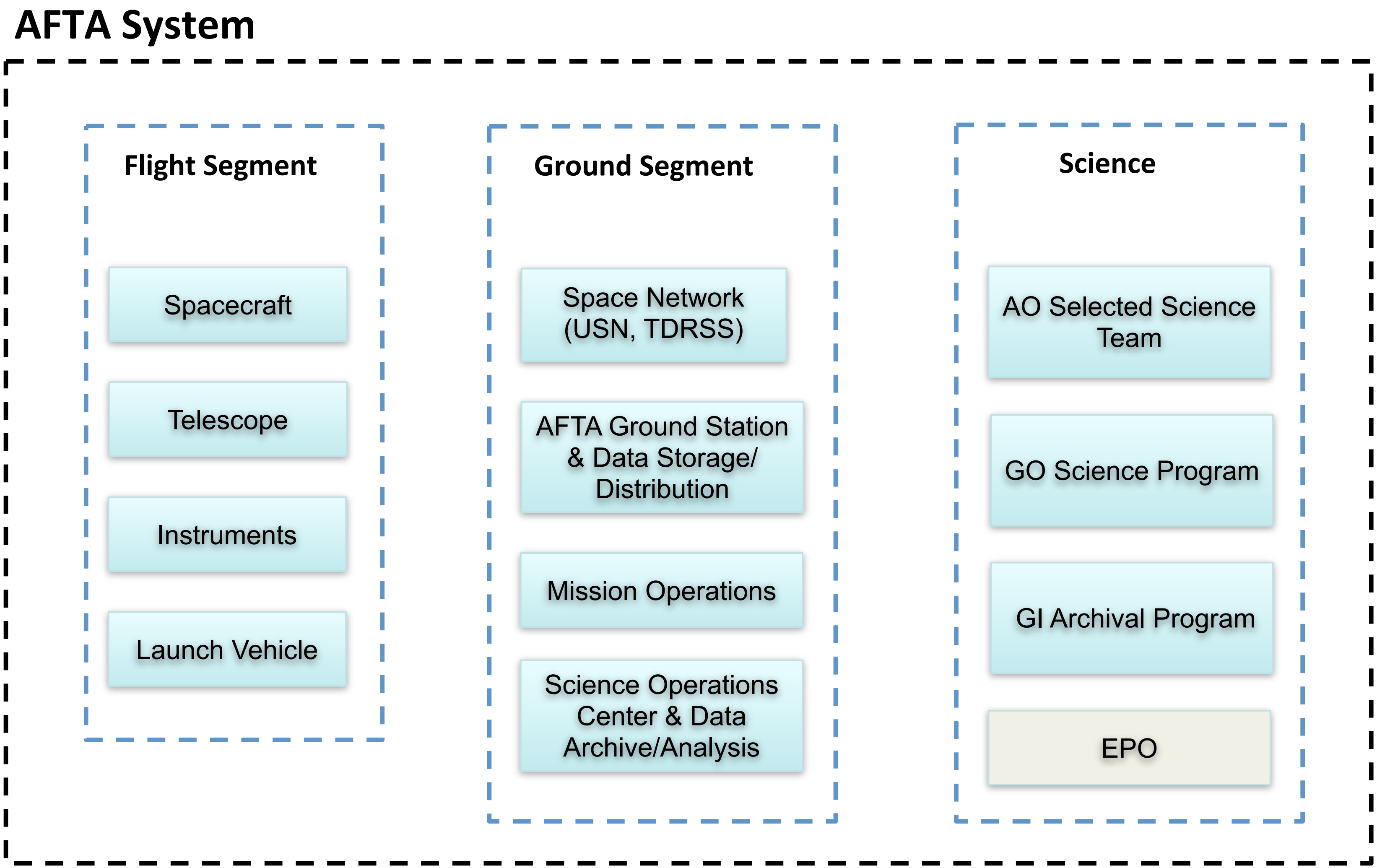
- *The AFTA DRM has a lower overall complexity & development risk than IDRM.*
- *The IDRM was costed at approximately 1.6B. CATE was 8% higher.*
- *While AFTA is significantly heavier, the increase in mass is primarily for propellant (to circularize) and the structure to support the large telescope. Neither of these items drive mission cost.*
- *The GSFC in-house GEO SDO spacecraft has been used as an analog for the WFIRST & JDEM DRMs for some time. It is even more appropriate as an analog now.*
- *While the size of the AFTA observatory is considerable, and the complexity of moving the observatory more challenging, similar operations with a 1.5m telescope would not have been without challenges.*
- *Summary – the savings due to the available telescope and the simplifications to the functionality of the widefield instrument should to first order offset the cost increase of larger structural mass. AFTA should be in family with previous IR survey DRM estimates.*

updated 4/8 12:05p

A: WFIRST-AFTA Development (Start Phase B FY15)



AFTA Mission Functional Elements



AFTA Life Cycle Cost Scenarios

- Two scenarios requested:

FY15 Start of Phase B

- LRD in 2021 followed by 5 year operational phase.
- Includes 7 months of funded schedule reserve.
- Includes 30% reserve on development phase and 5% reserve for operations phase.

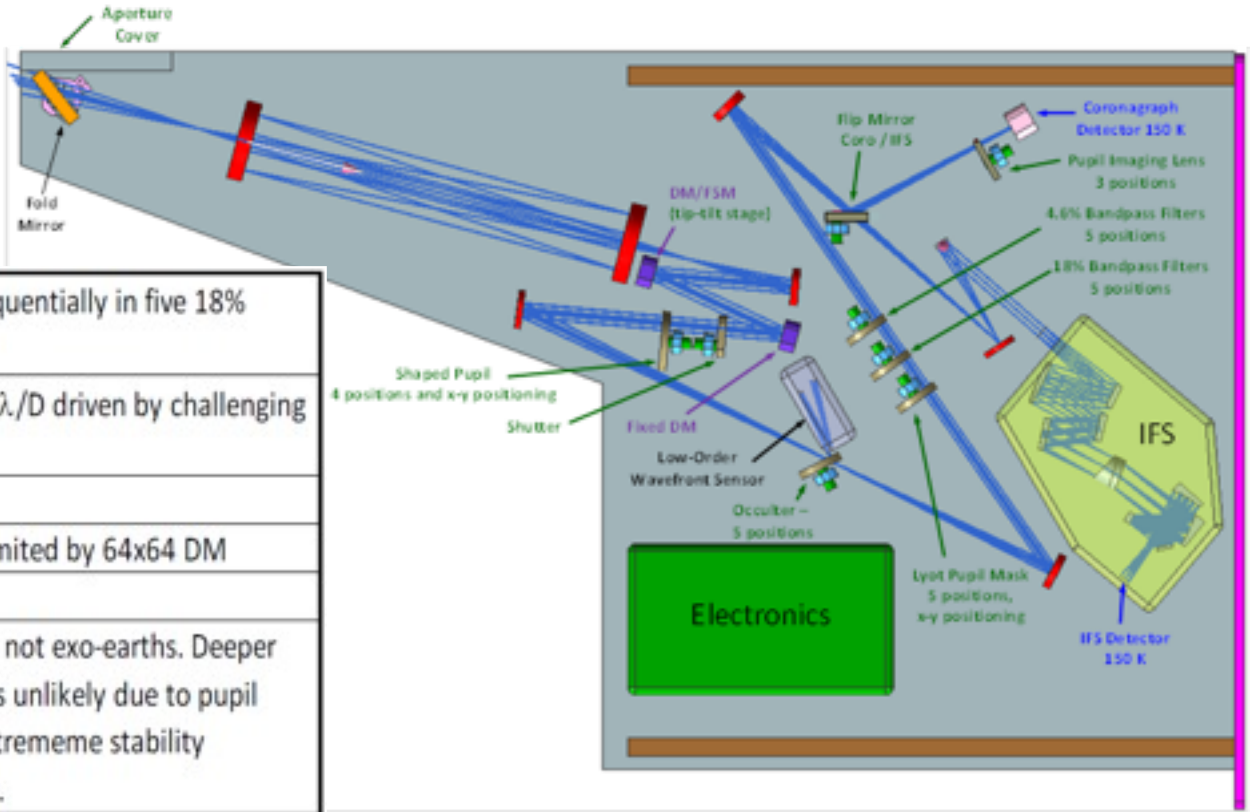
FY18 Start of Phase B

- LRD in 2024 followed by 5 year operational phase.
- Includes 7 months of funded schedule reserve.
- Includes 30% reserve on development and 5% reserve for operations phase.

Study Options

- Coronagraph
- Cost of Serviceability
- Optical Communications Option

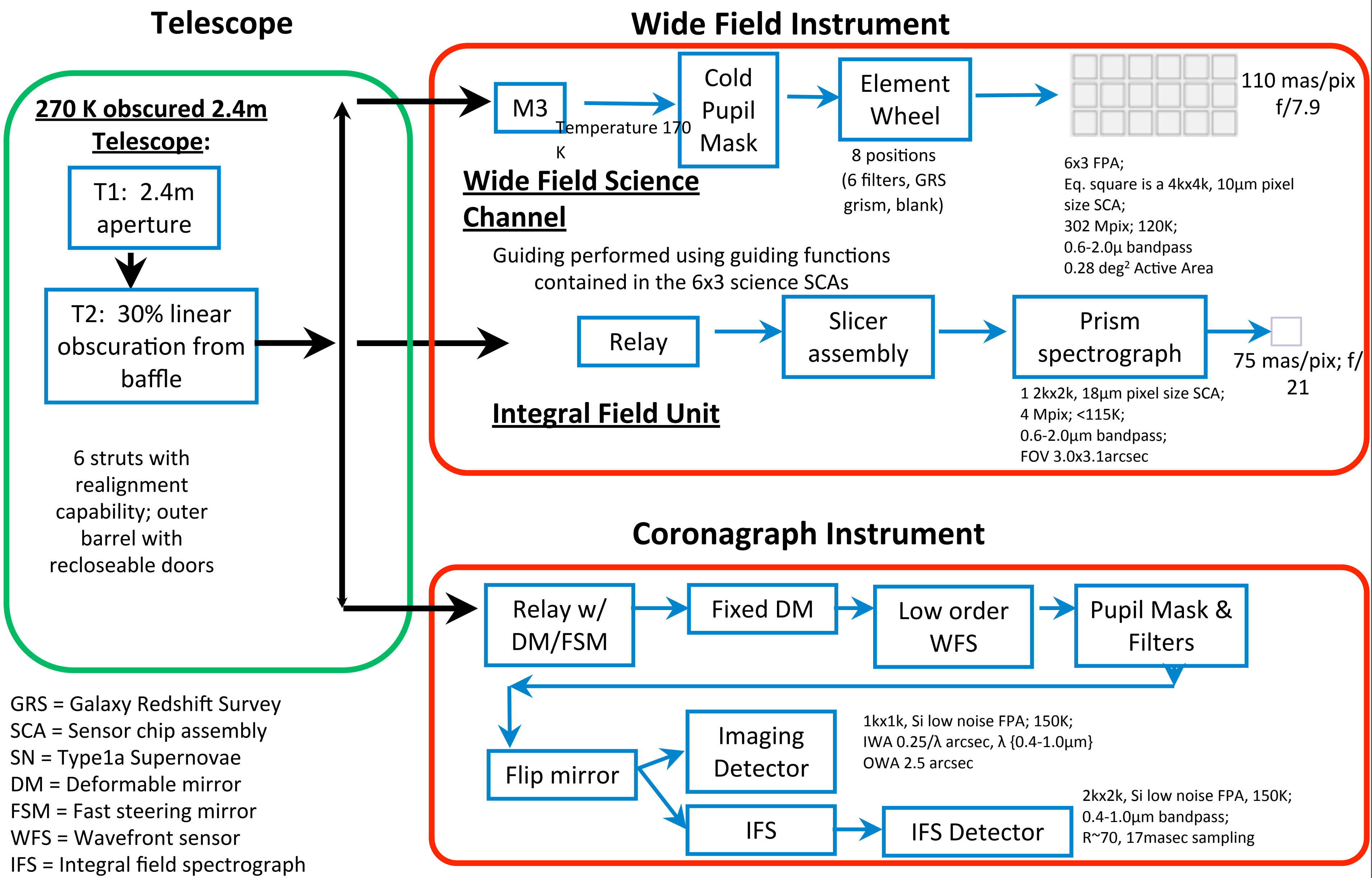
WFIRST-AFTA Coronagraph Concept



Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3 λ/D driven by challenging pupil
	250 mas	at 1 um
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 um
Detection Limit	Contrast $=10^{-9}$	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extrememe stability requirements.
Spectral Resolution	70	With IFS, ~70 across the spectrum.
IFS Spatial Sampling	17 mas	This is Nyquist for λ400 nm.

- **Representative coronagraph design shown for one of either a Shaped Pupil, Lyot, Vector Vortex coronagraph option for starlight suppression including polarizers.**
- **Design for PIAA coronagraph exists**
- **Future studies to narrow-down coronagraph to a single option**

AFTA WFIRST Payload Block Diagram

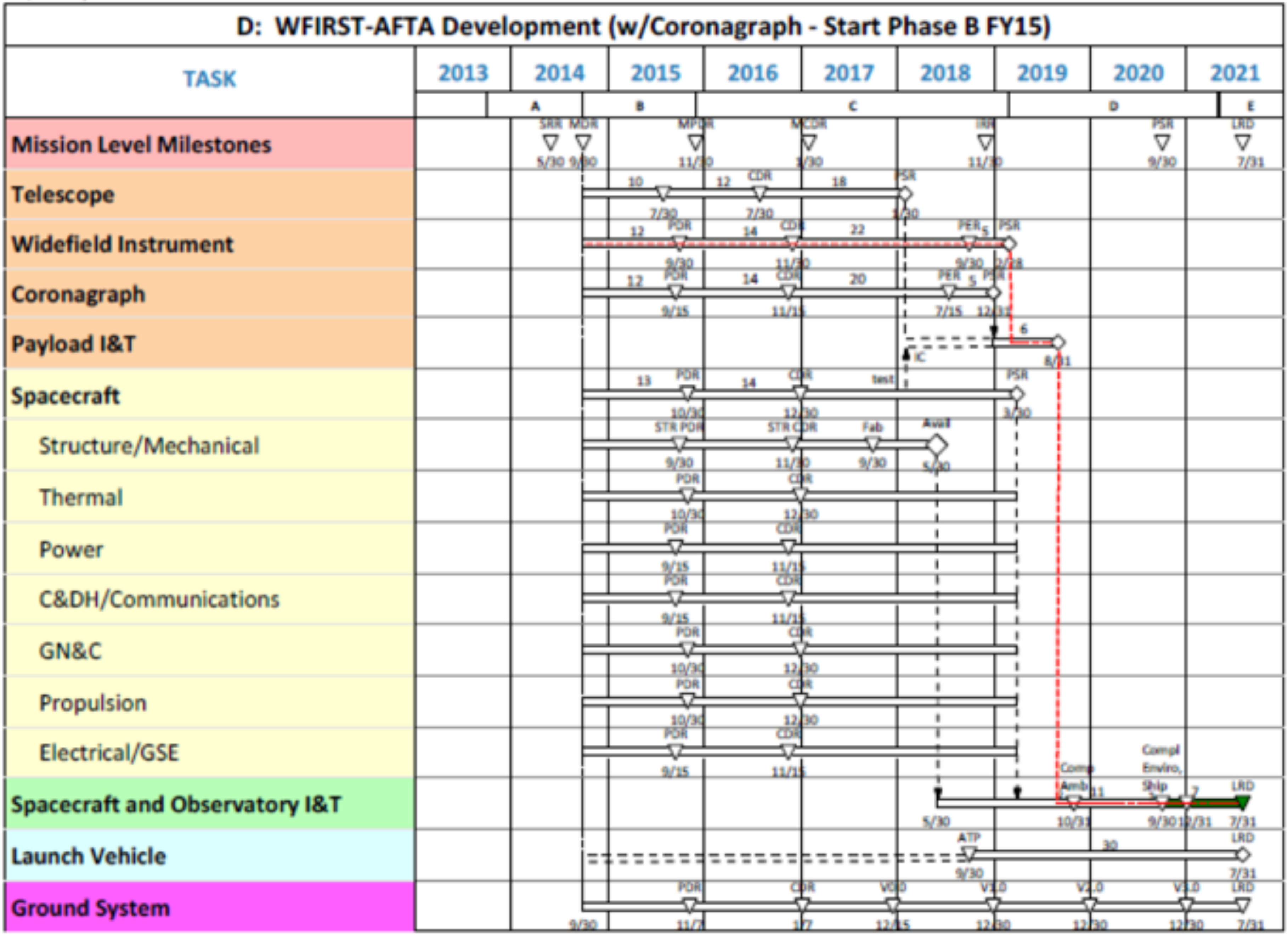


Observatory Performance Required by Coronagraph

- Interfaces within existing WFIRST-AFTA baseline capabilities
  - 80W power (CBE)
  - View to space for radiators
  - 29 Gbits/day (CBE)
  - Standard 1553 and SpaceWire interfaces

- Preliminary estimates for observatory stability appear achievable:
  - ➢ requires more detailed observatory design and analyses
  - ➢ If necessary, accept graceful degradation of coronagraph performance
    - 10 mas (1 sigma) jitter is within the coronagraph wavefront/tip-tilt pointing control system capability
    - mK–level telescope thermal stability to be studied through observatory active thermal management system design
    - 0.5 μm dimensional stability between telescope and coronagraph with contributions coming from instrument carrier latch for servicing and overall thermal stability.

4/12 1:50pm



Critical Path

Monday, January 13, 14

Coronagraph Costs

Approach

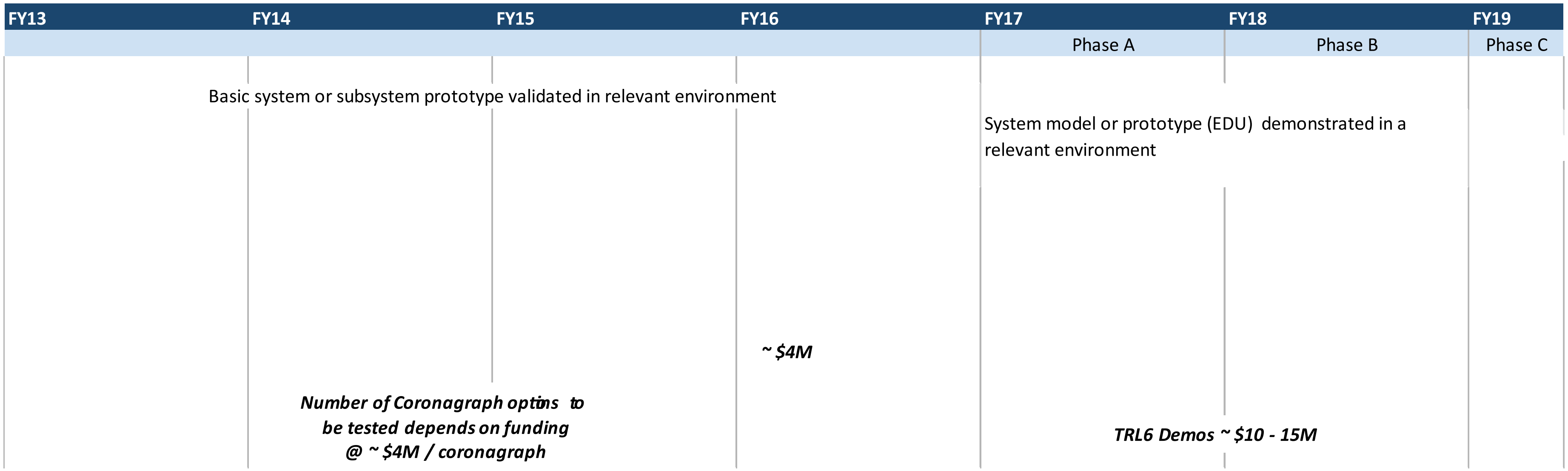
- Instrument costs were estimated with 4 independent models, all in agreement:
  - NICM System, NICM Sub-System, PRICE, SEER
- Assumes additional 35% mass contingency above current best estimate.
- Science costed at additional 15% of instrument development
- Allocated additional 30% cost reserve on total
- Assumes Technology matured to TRL 6 by PDR:
  - Technology development costed separately

Baseline Instrument Design – FY18 Start Phases B-D

	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	TOTAL
FY13 Dollars ($M)	0	0	0	9.5	33.6	38.4	38.4	10.2	7.7	0	0	0	138
Real Years Dollars ($M)	0	0	0	11.0	40.6	48.0	49.6	13.7	10.6	0	0	0	173
FTEs	0	0	0	22.1	78.4	89.7	89.7	23.9	17.9	0	0	0	322

❖ Costs above are for instrument only. Additional costs for 6th year of operations, 3 months of payload/observatory I&T, and any unique coronagraph accommodations.

WFIRST-AFTA Coronagraph Technology Development Path to TRL 6 by PDR (2018)



- Technology builds upon successful coronagraph demonstrations in the ExEP High Contrast Imaging Testbed at AFTA contrast performance of 10^{-9} & >10% bandwidths
- AFTA implementation brings new challenges for centrally obscured pupil coronagraphs
- TRL 6 Tech demonstration requires AFTA-like system integration & telescope simulator
- **Mission Directed Coronagraph Technology Program must start now!**
  - FY13 activities not currently in plan. Tech development to be submitted as overguide for PY15 PPBE
  - Plan does not address how technologies will be funded: Competed TDEMs or Directed Technology

Approach to developing AFTA Coronagraph on Accelerated Schedule (PDR 7/15)

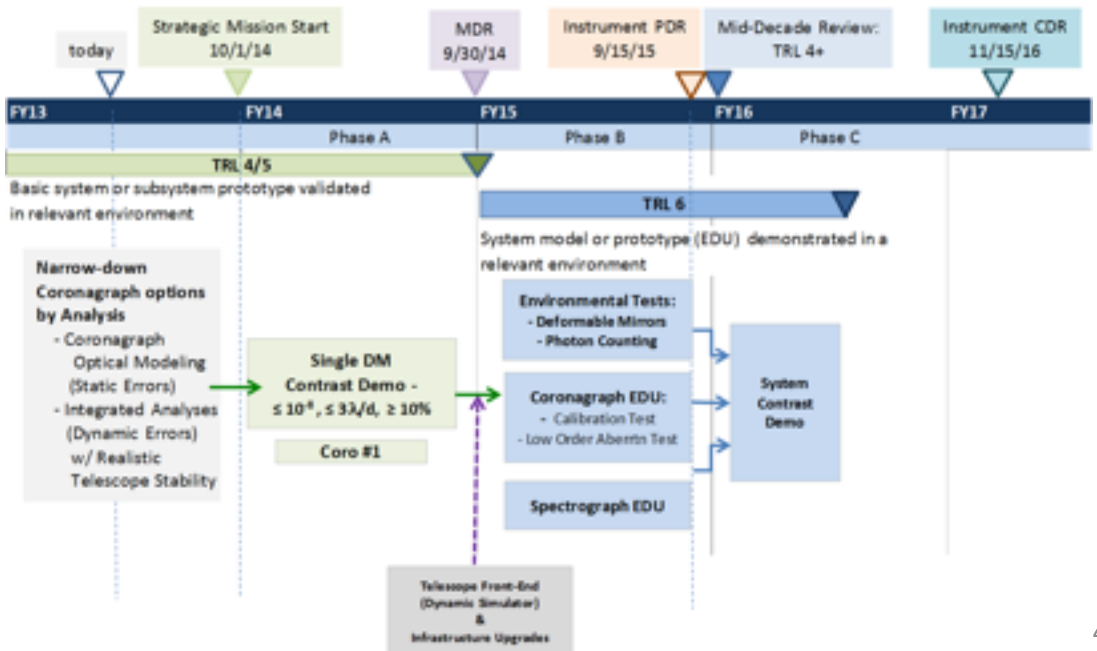
- Treat the AFTA Coronagraph primarily as a flight technology demonstration
  - Accept technical risk & graceful performance degradation:
    - At minimum, key components technologies will be brought to TRL 9 through flight: Deformable Mirrors, Detectors, Wavefront Sensing & Control, Instrument Pointing, Modeling
  - Perform science on a best effort basis w/ acceptable contrast ≤ 10^{-8} for Disk Science

- Adopt SMD Management Handbook standard #5.4.2.4 for Flight Technology Demos:

  http://www.nasa.gov/pdf/484498main_SMD%20HANDBOOK%2008-FEB-2008%20.pdf

Unlike science focused missions, technology demonstration missions may have technologies developed below TRL 5 during Phase B but must have all technologies at least to TRL 5 by the Phase B-to-C transition point

- Pick a single coronagraph mask design immediately based on models & analyses
  - Fast track the contrast performance demonstration w/ single deformable mirror
  - System demonstration after PDR



Cost of Serviciability

Cost of Serviceability

- The AFTA DRM arranges spacecraft and instrument hardware in robotically removable modules.
- In a conventional non-serviceable spacecraft, components are typically mounted on secondary structure, commonly panels.
- The change for AFTA is to make those panels readily removable. The spacecraft reference concept utilizes the attachment approach developed in the 1970's for the Multi-Mission Modular Spacecraft (MMS), and the instrument utilizes the mounting approach developed for HST in the 1980's.
  - Thus both approaches are low risk and high TRL (TRL-9).
- Spacecraft integration would proceed exactly as it would for a traditional "non-serviceable" spacecraft.
  - No unique GSE requirements.
- The estimate of the costs to incorporate serviceability included in the LCC is 18M. Based on both parametric and bottoms-up estimates.
- The cost of a servicing mission or the infrastructure to execute a servicing mission is not included in this LCC.

Optical Comm Option

AFTA Laser Comm Options

- AFTA laser communication implementation options use existing LCRD (Laser Communication Relay Demonstration) Mission hardware design

- Two implementation options- Technology demonstration vs primary science downlink

Technology Demonstration

-Supplements existing Ka-band science downlink to demonstrate laser comm in an operational environment
-Shared existing ground stations to reduce cost
-Estimate cost: ~$35M

WFIRST

LCRD Flight Optical Terminal
- Cost ~$30M

Heritage Ka-Band system for science data downlink

Share Existing LCRD Gnd Terminals
- ~$1M per year, 5 years

Primary Science Downlink

-Replaces RF system as sole source of science downlink, essential to science goals and mission success
-Dedicated grnd stations required for needed coverage
--Redundant system for reliability anc data coverage
-Estimated cost: ~$70M

WFIRST

Redundant LCRD Flight Optical Terminals
- Cost ~$60M

Dedicated Dual Gnd Optical Terminals
- ~$5M each, ~$10M total

Future Activities and Topics for Follow-on Study (1/2)

- Continue developing H4RG detectors; perform detailed characterization; package development detectors into a large focal plane array and perform performance tests. Most critical area for investment for minimizing overall risk of a WFIRST-2.4 mission.
- Assess the potential for pushing the wavelength cutoff for the wide-field instrument further into the red. Includes both telescope and widefield instrument.
- Determine requirements for on-orbit calibration of the widefield instrument and investigate options for internal instrument calibration.
- Optimize and refine the wide-field instrument and spacecraft designs and perform end-to-end structural/optical/thermal analyses of the observatory.
- Assessing potential for utilizing existing spacecraft hardware that is surplus from industry.
- Continue to assess launch vehicle options for potential lower cost opportunities that might become available.

Future Activities and Topics for Follow-on Study (2/2)

- Continue assessing coronagraph options. The requirements for coronagraphy with WFIRST-2.4m need to be refined, and a choice made of technology baseline architecture. Development work is required to improve the TRL of the coronagraph.
- Continue to refine and optimize the DRM strawman ops concept to maximize the science yield of the observing program within the mission lifetime.
- Continue refining the microlensing technique and studying the expected performance. Observational and theoretical/modeling studies are needed of event rates.
- Model the performance of the grism survey. The modeling work will aid in determining the resolution requirement, and effects of source confusion and cosmic rays.
- Study joint LSST & WFIRST science. Study the science that can be done by combining the LSST and WFIRST data sets. Develop briefing materials to inform the broader scientific community.

Summary

- *AFTA-2.4m – Unique & Exciting Opportunity!*
- **Extraordinary science reach – responsive to Decadal including a unique opportunity for coronagraphy technology advancement.**
  - **Exoplanets, dark energy, cosmic dawn, galaxy formation, quasar evolution, Milky Way, dark matter.**
- **Low risk -**
  - **Existing optical telescope assembly.**
  - **Extensive heritage for spacecraft (GSFC, GEO SDO experience) and instrument (WFC3).**
  - **Minimal technology development, maturing H4RG (JWST).**
- **Moderate cost, in family with past IR survey DRM cost estimates (as expected).**
  - **Optional coronagraph would add moderately to this cost, while adding a revolutionary new science capability.**
- **Launch in 6 ½ years is feasible.**
  - **Operations simultaneous with LSST and Euclid.**
  - **Excellent synergy with JWST.**

Back-up

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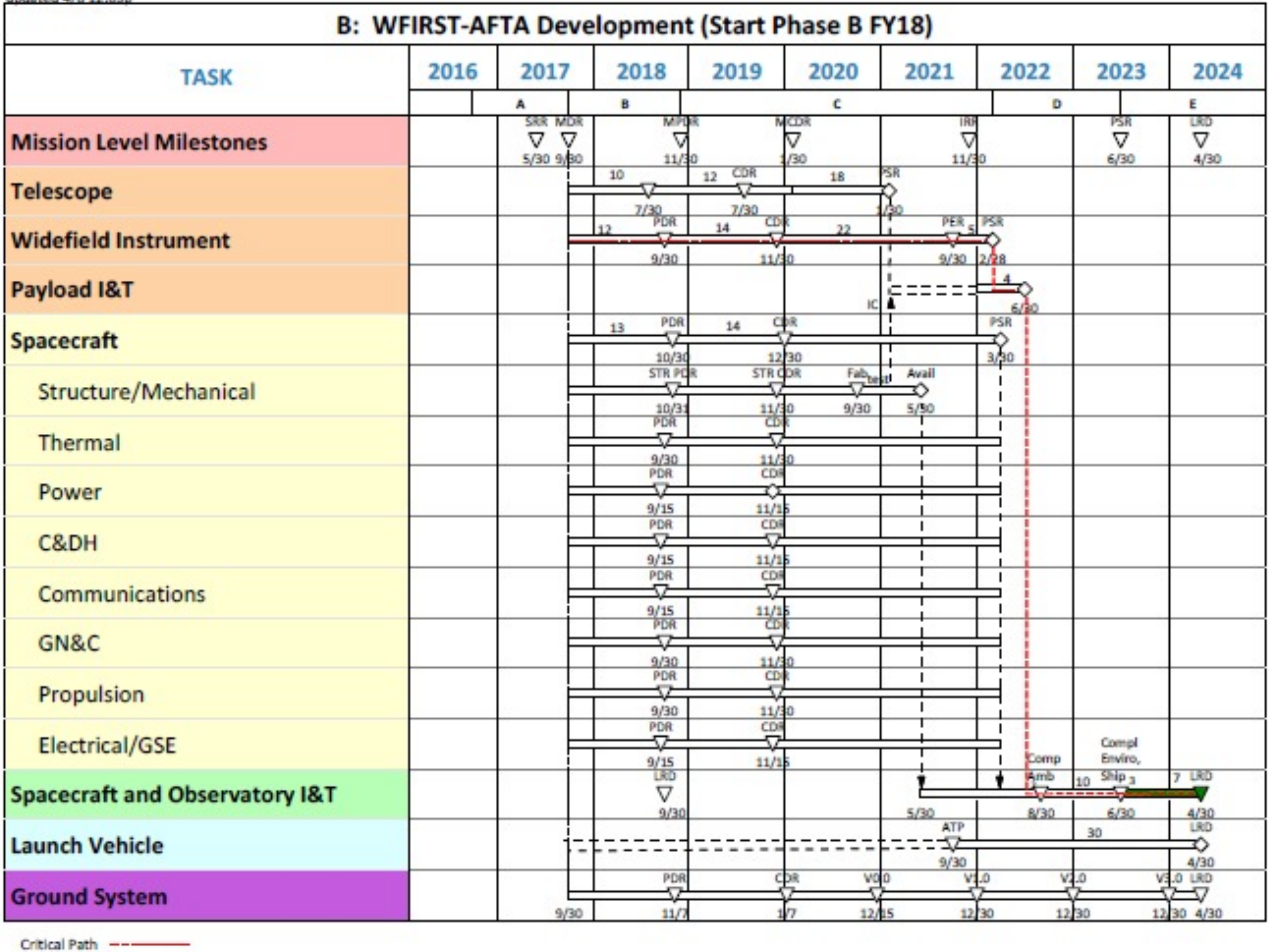

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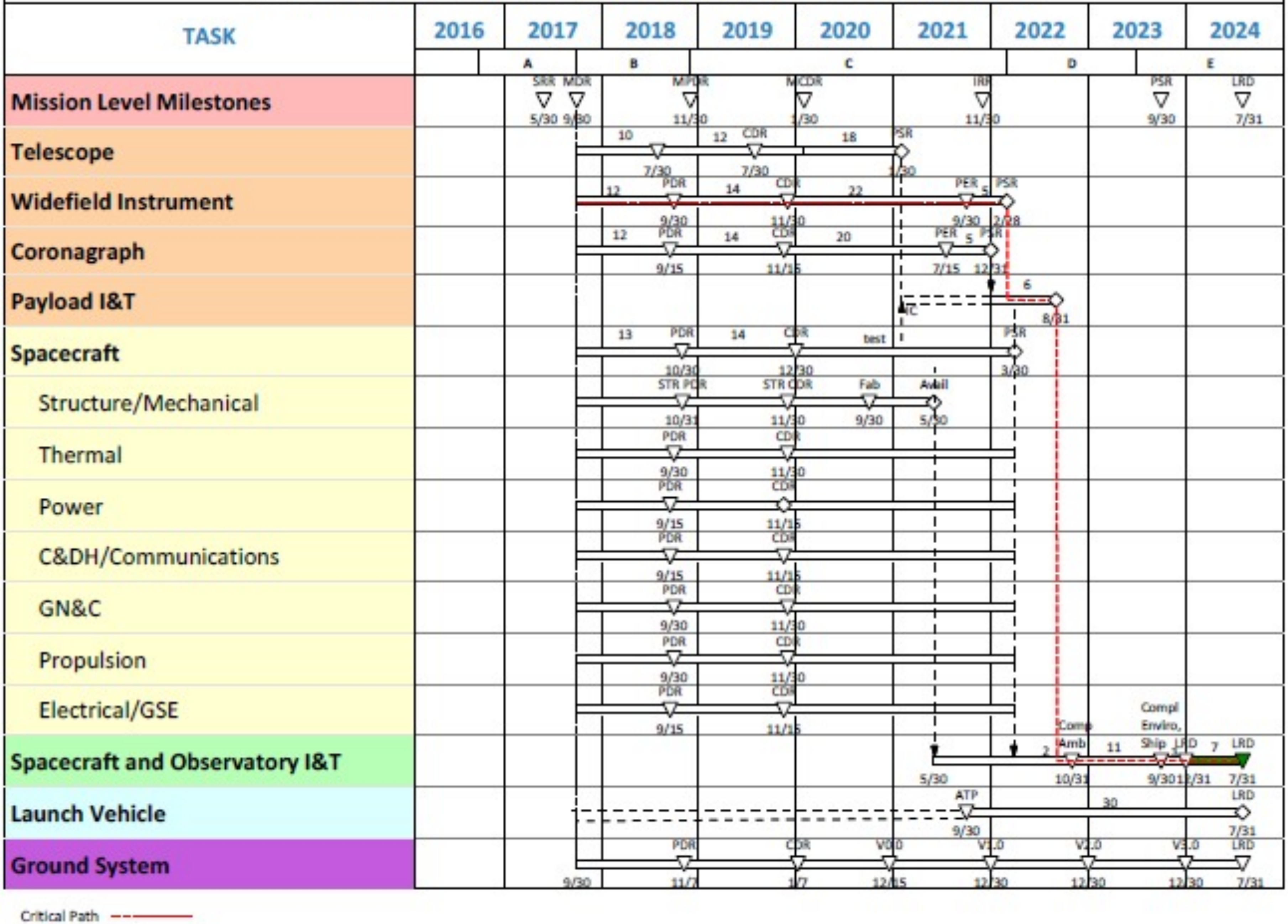
C: WFIRST-AFTA Development (w/Coronagraph Start Phase B FY18)

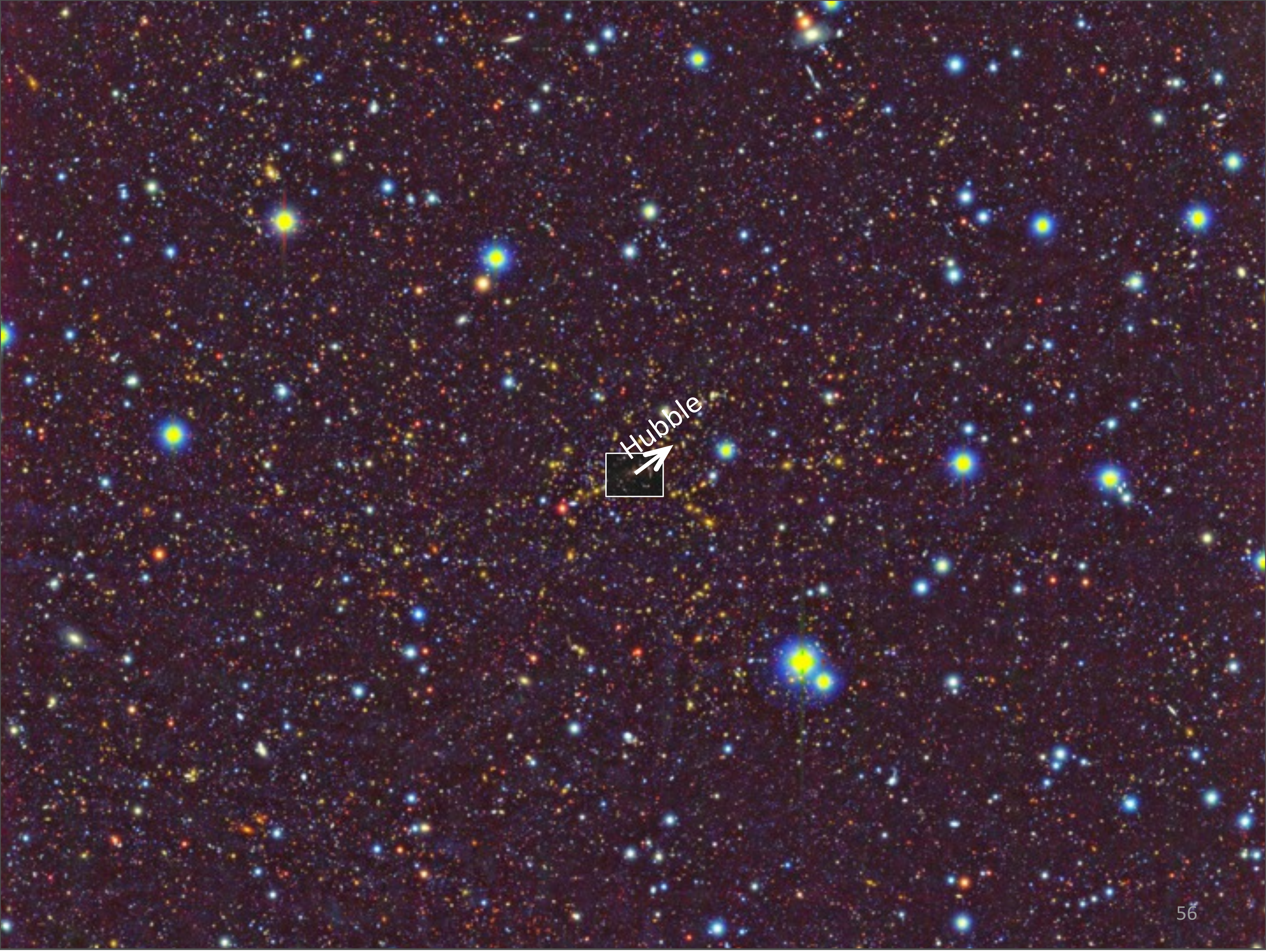


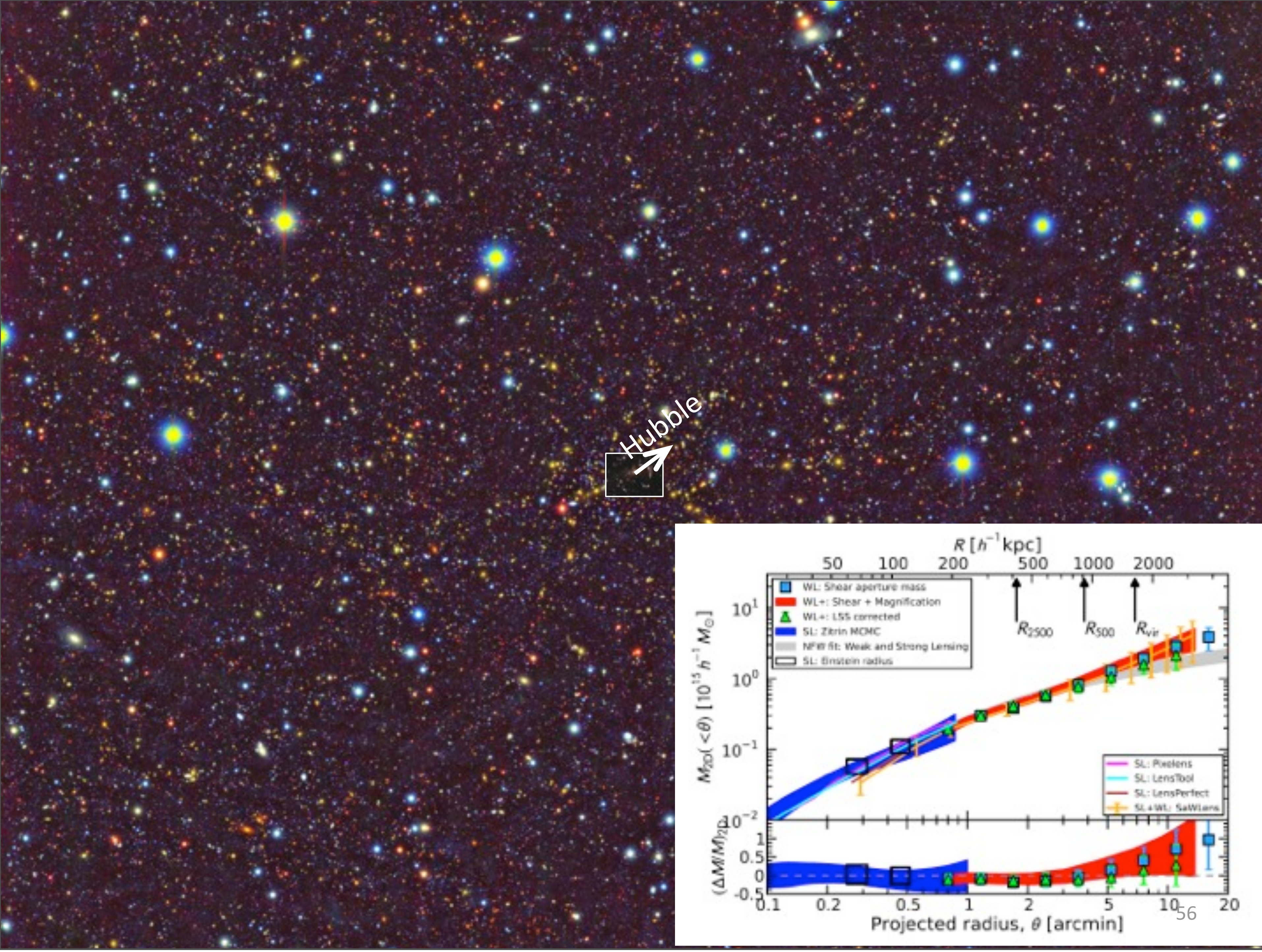
Back-up

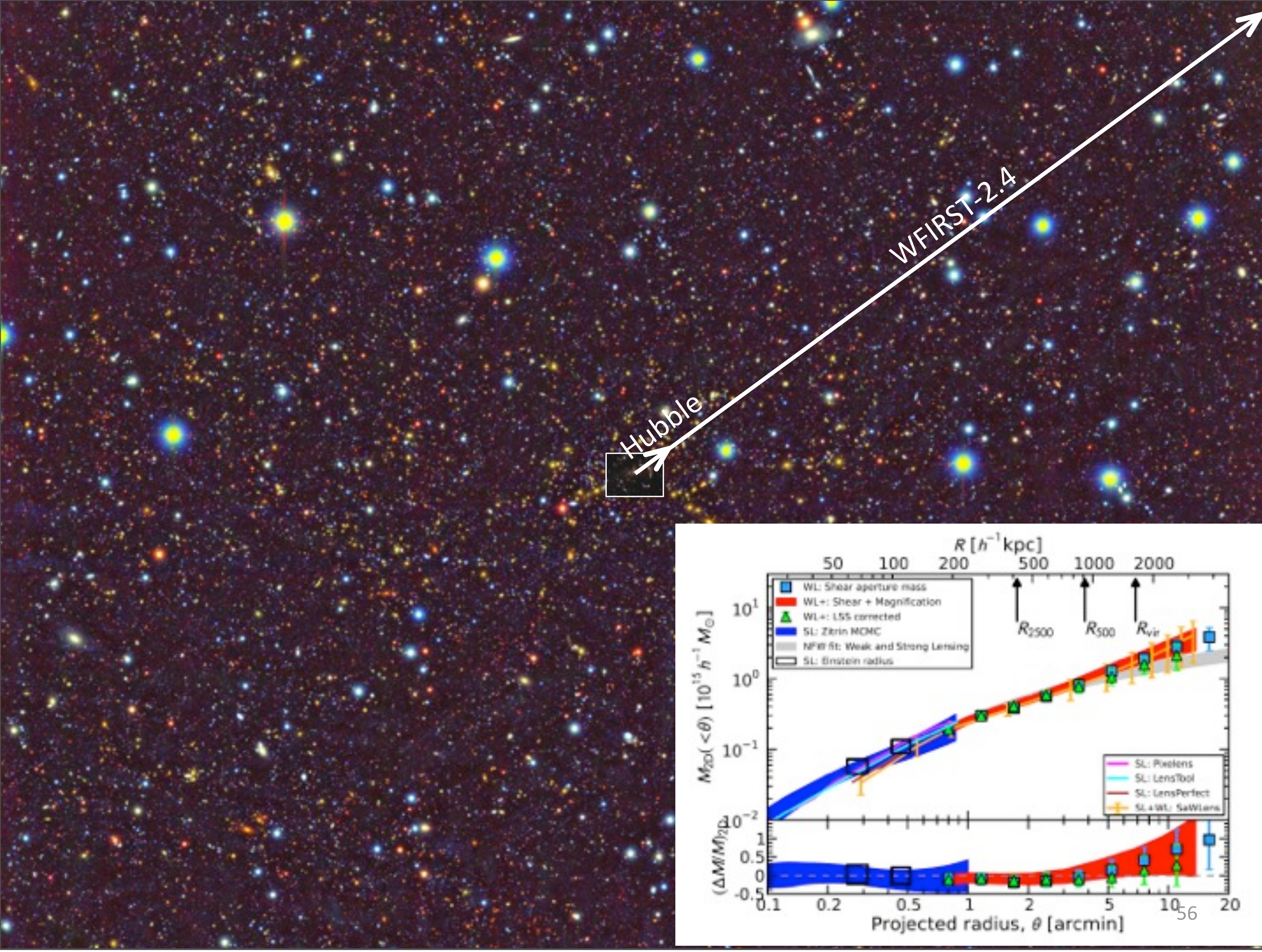
“Discover how the universe works, explore how it began and evolved, and search for Earth-like planets”
NASA Strategic Plan (p. 14)

AFTA-2.4m

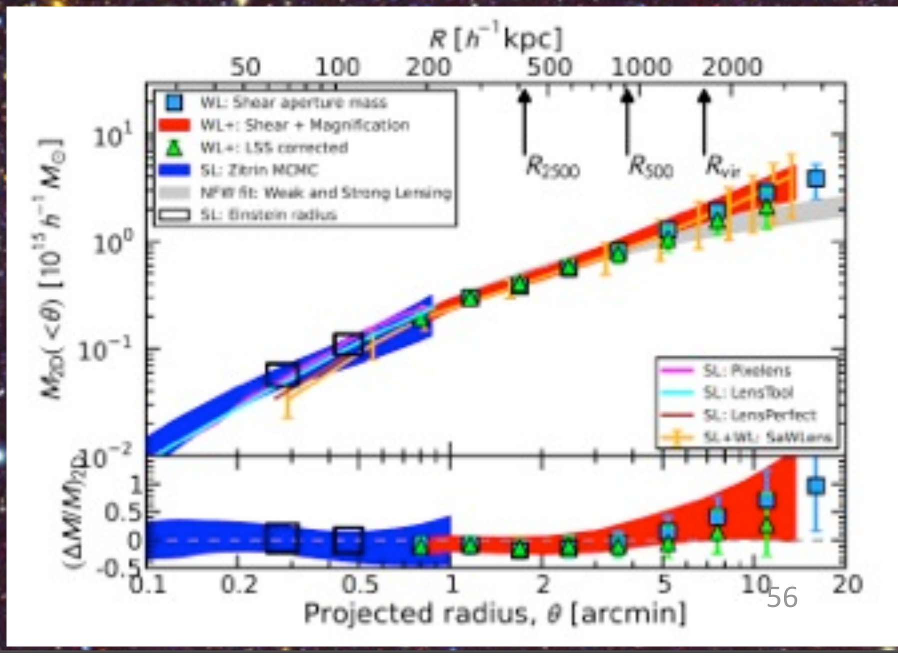
- Dark energy
  - * Accelerating expansion of the universe
  - * Growth of structure
- Exoplanet microlensing
- Exoplanet coronagraphy (optional)
- Galactic and extragalactic astronomy
- Guest Investigator & Observer program


Hubble


Hubble
R [h^-1 kpc]
50
100
200
500
1000
2000
WL: Shear aperture mass
WL+: Shear + Magnification
WL+: LSS corrected
SL: Zitrin MCMC
NFW fit: Weak and Strong Lensing
SL: Einstein radius
R2500
R500
Rvir
SL: Pixelens
SL: LensTool
SL: LensPerfect
SL+WL: SaWLens
M2D(<θ) [10^15 h^-1 M☉]
10^1
10^0
10^-1
10^-2
(ΔM/M)2D
1
0.5
0
-0.5
0.1
0.2
0.5
1
2
5
10
20
Projected radius, θ [arcmin]



WFIRST-2.4
Hubble
R [h^{-1} kpc]
50
100
200
500
1000
2000
WL: Shear aperture mass
WL+: Shear + Magnification
WL+: LSS corrected
SL: Zitrin MCMC
NFW fit: Weak and Strong Lensing
SL: Einstein radius
R_{2500}
R_{500}
R_{vir}
$M_{2D}(<\theta)$ [$10^{15}\,h^{-1}\,M_{\odot}$]
10^{1}
10^{0}
10^{-1}
10^{-2}
SL: Pixelens
SL: LensTool
SL: LensPerfect
SL+WL: SaWLens
$(\Delta M/M)_{2D}$
1
0.5
0
-0.5
0.1
0.2
0.5
1
2
5
10
20
Projected radius, θ [arcmin]



WFIRST-2.4 vs Subaru

30% larger field of view than SuprimeCam

5x greater depth in 1/3 time

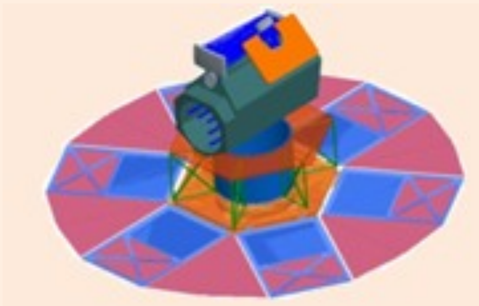
10x image sharpness

→ unprecedented maps of dark matter

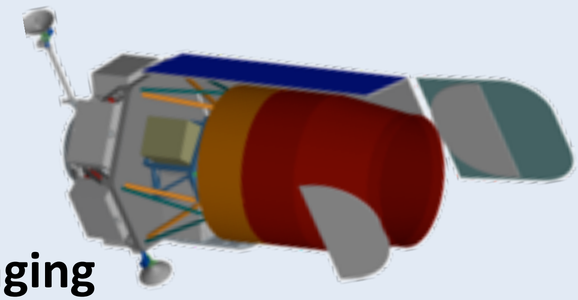
Evolution of WFIRST Concepts to AFTA

- **DRM1**
  - **1.3 meter off-axis telescope**
  - **150 Mpixels, 0.4 deg^2**
  - **5 year mission (15% GO time)**

- **DRM2**
  - **1.1 meter off-axis telescope**
  - **234 Mpixels, 0.6 deg^2**
  - **3 year mission (15% GO time)**



- **2.4m AFTA**
  - **2.4 meter on-axis telescope**
  - **288 Mpixels, 0.3 deg^2**
  - **Additional IFU for SN slit spectroscopy**
  - **Additional coronagraph for exoplanet imaging**
  - **5 year mission (25% GO time)**



Detector Layout on Sky

18 NIR detectors
0.11 arcsec/pixel   0.28 deg^2

Each square is a H4RG-10
4k x 4k, 10 micron pitch
288 Mpixels total

Slitless spectroscopy with grism in filter wheel
R_θ ~ 100 arcsec/micron

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WFIRST-AFTA Telescope Study Schedule 4/6/13

TASK	2012				2013					
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Science Defition Team										
Key Milestones										
Develop Level 1/2 Requirements										
Develop Science Observing Strategies										
Science Performance Assessments										
Mission Systems Analyses										
Optical & Mech I/F Definition & Analyses										
Radiation Assess, I/V Perf, delta-V assess										
Orbit Analyses/Fuel Budgets/ACS Analyses										
Thermal Analyses/Comm Downlink Budgets										
Observatory Design Concept Dev										
Spacecraft/Instrument Carrier										
Widefield Instrument										
Coronograph (JPL)										
Telescope (JPL)										
Cost & Schedule										
RESTORE Servicing Tasks (408)										
Develop Servicing Scenarios										
Dev 3-d Virtual Reality Sim										
Design & Fab Mech S/C & P/L Simulator										

AFTA can survey both deep and wide!

If early results suggest intriguing new insights into dark energy, AFTA is capable of doing even more dark energy science in extended operations by increasing sky coverage.